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OF THE
ROYAL AERONAUTICAL SOCIETY

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow

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NOTICES

Elections

The following Members were elected at a meeting of Council held on December 14th, 1926:—

Honorary Fellow.—Sir Charles Cheers Wakefield, Bart.

Fellows.—Air Vice-Marshal H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C., Group Captain H. M. Cave-Browne-Cave, D.S.O., D.F.C., Captain R. J. Goodman Crouch, O.B.E., Mr. H. Glauert, Captain G. T. R. Hill, M.Sc., Professor B. Melvill Jones, A.F.C., Sir Joseph Petavel, K.C.B., F.R.S., A.M.Inst.C.E., D.Sc., Mr. R. K. Pierson, B.Sc., A.M.Inst.C.E., Major J. D. Rennie, A.M.Inst.C.E., Mr. H. R. Ricardo, A.M.Inst.C.E., M.I.A.E., M.N.E.C.I.E., M.S.A.E., Major G. H. Scott, C.B.E., A.F.C., Mr. H. O. Short, Mr. T. O. M. Sopwith, C.B.E., and Mr. R. V. Southwell, F.R.S.

Associate Fellows.—Mr. A. H. Hall, M.Inst.C.E., M.I.Mech.E., Mr. W. Lind-Jackson, B.Sc., Mr. R. L. Preston, Mr. H. B. Taylor, F./O. W. C. Venmore, B.Sc., and Mr. H. Weakley.

Associates.—Mr. E. W. Dodds, Mr. C. E. Dodge, Mr. V. S. Gaunt, Mr. A. P. Hunt, Mr. J. Jarvis, Mr. A. S. R. Lewin and Flt. Sgt. R. A. Stavey.

Students.—Mr. H. T. Edgecombe, Mr. E. E. Hughes-Williams, Mr. J. Remfry, Jun., and Mr. J. N. Richmond.

Member.—Captain L. W. Charley.

The following have been transferred from the former Scottish Branch:—

Fellows.—Mr. T. Blackwood Murray, D.Sc., M.Inst.C.E., and Air Commodore J. G. Weir, C.M.G., C.B.E.

Associate Fellow.—Sir John Reid, D.L., J.P.

Members.—Mr. J. F. Fyfe-Jamieson and Mr. R. Dunlop.

Endowment Fund

The attention of members is called to the letter of the Duke of York which appears on page 4.

Data Sheets

Arrangements have been made for the issue of data sheets. These sheets will contain abstracted information of use to ground engineers, draughtsmen and all those engaged in the practical side of the industry. These data sheets will be issued at frequent intervals, and it is to be hoped that all those who wish for such information will write to the Secretary, so that those sheets for which there is a demand are printed as soon as possible.

The data sheets will be printed on an 8 × 5in. page, convenient for note books, with a wide left hand margin for insertion in the note books. They will enable anyone in the industry to collect together, in a convenient, condensed

and usable form, much of the information now scattered in various works of reference, B.E.S.A. specifications, private note books and the like.

It is hoped that those who have any specialised or unpublished information of any kind which would prove useful to other members of the industry, will communicate with the Secretary with a view to its publication.

The data sheets will be issued to all members of the Society upon application. Any further information with regard to them can be obtained on application to the Secretary.

Extracts from the Technical Press

On pages 81—94 are reprinted, by permission of the Air Ministry, extracts from the Technical Press of the world. These extracts will be published in the Journal as issued.

Branch Section

Beginning with this issue of the Journal, a section dealing with the branches of the Society will be printed monthly. It appears this month on pages 95—102.

Wilbur Wright Memorial Lecture

Professor Prandtl has consented to give the Wilbur Wright Memorial Lecture, 1927, on some date in May to be announced later.

Donation

The Council acknowledge gratefully a donation of one guinea from Sir Charles Bright towards the Elliott Memorial.

Elliott Memorial Prize

The Council have decided to give an annual prize of five guineas for a paper by a boy being trained at Halton, as a memorial to the late Mr. R. B. Elliott, who contributed so greatly to the success of Sir Alan Cobham's flights to India, South Africa and Australia. The subject of the paper will be decided in collaboration with the Commanding Officer at Halton and further particulars will be announced later.

Secretary

Mr. J. Laurence Pritchard has been appointed Secretary of the Royal Aeronautical Society as from January 1st, 1927.

Forthcoming Events

Thursday, January 6th, 1927, 6.30 p.m.—At the Royal Society of Arts, Major B. C. Carter, A.R.C.Sc., D.I.C., A.F.R.Ae.S.: "Dynamic Forces in Aircraft Engines with Particular Reference to Torsional Vibration, Inertia Loading, Balance and Reactions on Mountings."

Tuesday, January 18th, 6.0 p.m.—In the Library, Informal Discussion on "Oil Cooling." The discussion will be opened by Mr. A. H. R. Fedden.

Thursday, January 27th, at 7.0 p.m.—In the Library, Students' Meeting, Lecture and Discussion: "The Possibilities of Metal Construction with Special Reference to the Metal Skin," by Mr. R. M. Hayes.

Thursday, January 20th, 6.30 p.m.—At the Royal Society of Arts, Mr. H. Glauert, Fellow: "The Theory of the Autogiro."

Saturday, January 29th.—Visit to Croydon Terminal Aerodrome. Afternoon. Mr. H. R. Gillman, A.F.R.Ae.S., will show the party round.

Tuesday, February 1st.—Joint Meeting with the Institution of Automobile Engineers, at 7.0 p.m., at the Royal Society of Arts. Mr. A. H. R. Fedden, Fellow: "Supercharging for Aero Engines."

J. LAURENCE PRITCHARD, *Secretary.*

THE ROYAL AERONAUTICAL SOCIETY

Reception and Lecture by Sir Alan Cobham

There was a large and distinguished gathering at a Reception held in the King Edward VII. Rooms at the Hotel Victoria, Northumberland Avenue, London, W.C.2, on Monday, October 25th, under the auspices of the Royal Aeronautical Society, to meet Sir Alan and Lady Cobham, the former having recently completed his pioneer flight from this country to Australia and back.

Among those present were:—Captain P. D. Acland; Mr. and Mrs. H. A. Adamson; Miss G. E. Adamson; Miss P. M. Allday; Mrs. Harold Armstrong; Miss Auld; Mr. and Mrs. W. L. Avery; Professor L. Bairstow; Mr. and Mrs. R. M. Balston; Major T. M. Barlow and Mrs. Barlow; Miss Barwood; Major Cavendish Bentinck; Major and Mrs. B. Binyon; Lieut. Bos; Mr. T. Beale; Miss Birkett; Miss R. Beale; Mr. and Mrs. G. E. Beare; Air Vice-Marshal Sir Sefton Brancker; Major F. H. Bramwell and Mrs. Bramwell; Miss D. M. A. Bramwell; Mr. and Mrs. Griffith Brewer; Miss Betty Brewer; Mr. Cyril G. Brewer; Group Captain E. F. Briggs and Mrs. Briggs; Colonel Whiston Bristow; Flight Lieut. G. M. Bryer; Miss D. J. Byford-Thomas; Major J. S. Buchanan; Major G. P. Bulman; H.H. the Maharajah of Burdwan; Miss A. Burrows; Mr. C. W. Burrows; Mr. Capell; Mrs. Carlton-Walker; Capt. Carlton; Capt. L. W. Charley; Mr. T. W. K. Clarke and Mrs. Clarke; Mr. C. V. Coates; Miss Theodora Coates; Sir Alan and Lady Cobham; Sir Robert and Lady Waley Cohen; Mr. and Mrs. C. G. Colebrook; Miss Collier; Sir Joseph Cook; Mr. and Mrs. Chas. Cooper; Squadron Leader de Courcy; Mrs. de Courcy; Mr. J. R. Cowper; Sir Edward Crowe and Lady Crowe; Mr. H. E. Crowther; Mr. E. V. Dolby; Mr. W. Dare; Eng. Vice-Admiral Sir Robert Dixon, R.N., and Lady Dixon; Miss Doris Edwards; Lieut.-Colonel N. Eliot and Mrs. Eliot; Mr. J. P. Emerson; Lieut. Cdr. T. K. Elmsley, A.F.C., R.N., and Mrs. T. K. Elmsley; Mr. A. E. Fanstone and Mrs. Fanstone; Miss F. Farrington; Miss A. Farrington; Mrs. A. Fleming; Capt. F. Freeman; Mr. J. S. Fulton; Mrs. Galsworthy; Mrs. Gault; Capt. Gladstone; Lady Goulding; Mrs. Edward Gray; Mr. W. E. Gray; Mr. Griffiths; Major F. M. Green and Mrs. Green; Mr. R. W. Green; Mr. C. G. Grey; Mr. J. D. Haddon; Miss Haldane; Mr. Hall; Mr. G. W. Hart; Mr. and Mrs. Hart-Dyke; Sir James Heath; Major H. Hemming and Mrs. Hemming; Mr. C. S. Hilton; Mr. C. Hirai; Mr. Alan Hinshelwood; Mrs. Hinshelwood; Mrs. Hill Hodgson; Mr. and Mrs. E. Hopkins; Miss M. M. Hopkins; Mr. Ibbotson; Mr. and Mrs. Iles; Professor C. I. Jenkin; Miss Kay; Major D. H. Kennedy; Dr. and Mrs. Keneley; Mr. J. E. G. Labey; Major Lamplugh; M. E. Lanzerotti-Spina and Mrs. Lanzerotti-Spina; Mrs. Leake; Mr. H. Leitner; Sir William Letts, Bart.; Mr. David Longden; Sir Francis and Lady McClean; Colonel F. C. Macdonald; Colonel C. L. Malone; Mr. W. Cooper Matthews; Brig.-General H. O. Mawle and Mrs. Mawle; Mr. and Mrs. R. M. Mayo; Lieut.-Colonel J. Moore-Brabazon, M.P.; Capt. D. Nicolson and Mrs. Nicolson; Dr. Humphrey Nockord; Mr. and Mrs. Nigel Norman; Mr. R. B. North; Mr. T. P. O'Connor, M.P.; Squadron Leader O'Neill and Mrs. O'Neill; Miss O'Shea; Miss Ethel O'Shea; Mr. and Mrs. Handley Page; Baroness Palmstierna; Major Cochran-Patrick and Mrs. Cochran-Patrick; Mr. C. Spencer Payne; Commander H. E. Perrin; Sir Ernest Petter; Mr. H. Murray Philipson; Mr. C. A. Pike; Mrs. W. M. Pike; Lieut. Rupert Preston; Mr. and Mrs. Pritchard; Miss Richmond; Mr. H. G. Riddle; Mr. T. B. Ringwood; Mrs.

Ringwood; Engr. Lieut.-Comdr. L. Robinson and Mrs. Robinson; Capt. Rogers; Mr. and Mrs. W. H. Sadgrove; Miss O. St. Barbe; Mr. F. E. N. St. Barbe; Mr. R. Seko and Mrs. Seko; Colonel the Master of Sempill and the Hon. Mrs. Forbes Sempill; Mrs. Shaw; Capt. F. Shepherd; Mrs. Clare Sheridon; Sir Mortimer Singer and Lady Singer; Cdr. H. M. Smart, C.M.G., O.B.E., and Mrs. Smart; Major W. H. Smith and Mrs. Smith; Lieut.-Colonel the Hon. R. E. Snowden; Mrs. Snowden; Mr. T. O. M. Sopwith; Hon. Mrs. Sopwith; Lieut. the Hon. J. P. Southwell; Miss Spear; Mr. G. A. T. Stenning; Mr. D. Stevenson; the Duke of Sutherland; His Excellency the Swedish Minister; Sir John and Lady Sykes; Mr. J. V. Tabb; Cmdr. Y. Taji and Mrs. Taji; Capt. and Mrs. Taylor; Dr. Thole; Mr. Hadley J. Thomson and Mrs. Thomson; Capt. Cyril Turner and Mrs. Turner; the Very Rev. Dr. John G. Vance; Capt. C. D. Villarey; Sir Charles and Lady Wakefield; Sergeant Ward; Mr. E. G. Walker and Mrs. Walker; Dr. H. C. Watts; Squadron Leader J. K. Weller; Mr. D. Hollis Williams; Mrs. Williams; Miss K. Wilson; Mr. A. H. Wilson; Mr. and Mrs. C. W. Wimbury; Mr. and Mrs. H. E. Wimperis; Mr. R. McKinnon Wood; Mr. and Mrs. Norman Wright.

SIR ALAN COBHAM'S LECTURE

Following the Reception, Sir Alan Cobham delivered a lecture in which he described his Australian flight, paying particular attention to its techincal aspects. The lecture was illustrated by a large number of lantern slides. He was accompanied on the platform by Air Vice-Marshal Sir W. Sefton Brancker, K.C.B., and Colonel the Master of Sempill, A.F.C., President and Chairman respectively of the Royal Aeronautical Society.

Air Vice-Marshal Sir W. SEFTON BRANCKER, K.C.B., introducing Sir Alan, said:—Your Excellencies, Your Grace, My Lords, Ladies and Gentlemen: In the first place I have to announce that H.R.H. the Duke of York is extremely sorry that, owing to his absence from London, he cannot be here to-night, but he has sent me a letter to express his sympathy with the Royal Aeronautical Society. He is one of our patrons, and the Prince of Wales is the other. The letter is as follows:—

17, Bruton Street,
Mayfair, W.1.
October 23rd, 1926.

"Dear Sir Sefton Brancker,

"I very much regret that I will be unable to be present at the Royal Aeronautical Society's Reception on October 25th.

"I am proud to feel that the Prince of Wales and I share between us the honour of being Patrons of the oldest aeronautical body in the world, and it would have given me the greatest satisfaction to have been able to attend the Reception.

"The work of the Society is growing constantly in magnitude and importance. Its position can be maintained and improved only if all those connected, either directly or indirectly, with aeronautics give their fullest support.

"The munificent gift from the Guggenheim Trust Fund of the U.S.A. will in a measure enable the scope of the Society's activities to be widened, and I hope that those public-spirited persons or bodies who have in the past done so much to help forward our other great Societies will give assistance so that a substantial Endowment Fund may be established.

Yours sincerely,
(Signed) ALBERT."

I think that is a very satisfactory letter. Most of aviation is new, but this Society is now 61 years old—you may remember that we celebrated our 60th anniversary last January—and it is the oldest aeronautical institution of any sort in the world. Lately we were accused of being a highbrow Society, but we have altered our constitution so as to combine the scientific man with the real practical man, the man who is working on aviation both in the air and on the ground to-day. What we want now is greater membership, and I hope that at the present Imperial Conference we may be able to arrange for branches to be established in the overseas Dominions and in the Crown Colonies. Under the new constitution we have arranged a system of branches, under which we give them everything and they give us nothing (laughter).

Now, for about the eighth or ninth time during the last fortnight, I have to introduce Sir Alan Cobham, and I am extremely glad that to-night I have something new to say. It is that the Council of the Royal Aeronautical Society has elected him to the highest grade it can; it has elected him an Honorary Fellow of the Society (applause). In addition, we have elected Sergeant Ward and Mr. Capell Life Associates of the Society (renewed applause), and hope that they will all really help the Society in its great future developments. But we must not forget Elliott, who died gloriously just as the rewards were within his grasp, as did so many others during the Great War, and we are considering very seriously what we can do to perpetuate the name of Elliott as one of the greatest ground engineers the world has ever seen. It is up to us to do it, and we are trying to evolve a method of doing it in the proper way.

Coming back to the lecturer, he had said the other day that about 1910 Paulhan flew to Manchester for the first time, and gained a reward of £10,000. On that basis, if you tot up the amount of flying Sir Alan has done, he ought to be one-and-a-half times a millionaire by now (laughter). There are two great things to remember about what Sir Alan has done. Many great feats have been accomplished by our friends in America, France, Italy, and other parts of the world since the end of the War, but whereas the great flights of the aviators of other countries have been supported financially by their Governments, Sir Alan Cobham has accomplished all his great feats on private enterprise. That is one great difference. Perhaps other Governments have greater imagination than ours. Sir Alan has asked me to try to get the Government to support his flights, but the Government would not support them. The only thing they would do was to pay him a small fee to take me to Rangoon and back, and that is the very best I have been able to do for him (laughter). His other feats have been the result of his own energy and initiative, and he has inspired various patriotic supporters to finance his great voyages of the last three or four years. We ought to be proud of hm, and as a Government servant, whose duty it is to look after the interests of the taxpayers, I am also proud of him. Another great thing he has done is to spread the good word of international understanding everywhere in Europe. Wherever I go now, everybody knows Cobham. They like him; they think he is a typical Englishman—I think probably they are right—and after seeing Cobham for a couple of days they come to the conclusion that we are not such a bad race after all. He has that wonderful power of getting people to do things through the medium of a language they do not understand; whether they speak Polish, Russian, German, Italian or Hindustani, they understand what he wants every time. Therefore, I think he is a great international asset; not only is he creating our imperial communications, but he is helping to achieve the great object which most of us have at heart, namely, international understanding and peace in Europe.

Sir ALAN COBHAM said :—In the first place I want to say how highly honoured I feel in having been elected an Honorary Fellow of this very great Society, and I can only hope that I may be able to help, as suggested by Sir Sefton Brancker.

The story I have to tell you to-night is really a story of difficulties. I want to give you some idea of what we really found out by going to Australia, some of the difficulties we encountered, and how we overcame them. First of all, let me tell you the reasons for the flight. I think there were three reasons. As you know, the only way in which we can make progress in aviation in these days is to enlist public support; we want to get public opinion in favour of aviation, because public opinion controls everything, and if we have the public in our favour they can force the powers that be. The only means by which we can get the public on our side is to hand out sound propaganda in regard to aviation in general. Therefore, I imagined that a flight to Australia and back, going steadily, and making a survey, would have a more or less lasting effect upon the public, who would, in consequence, realise that this flying game is not such a stunt as they at first imagined, and would give their support. If we get that we shall get Government support. Therefore, that was the first object. The next object was to find out how an aeroplane and an engine behaved in a flight between England and Australia, under all sorts of climatic conditions. The third object was to examine the possibilities of the different air routes between England and Australia, to find out whether air lines might pay, whether they would be useful to the country and the Empire—to gather information of that sort for the benefit of those who come along afterwards.

It is not much use flying around an aerodrome; my view is that one can fly around an aerodrame for years and never really get down to tacks, and it is not until you push out into the blue, when an aeroplane has to stand alone, as a unit unto itself, that you really find out the troubles and difficulties to be encountered. I will give you a simple illustration. We have an antiquated method of filling a machine with petrol. There is a tank with a hole in it, and through that hole you pour the petrol. People learned that about 4,000 years ago. At any rate, that is the method, no matter how you are going to climb up to fill the tank. It may be situated so that you cannot get at it. Before I started one flight I asked the foreman on the aerodrome how I was going to fill the petrol tank, and he said I must get a ladder. I replied, "What! Get a ladder in the middle of the Sahara?" That will illustrate that you never get down to tacks until you get away from home and away from all organisation.

The route on this Australian flight covered 28,000 miles, there and back. You have heard how the flight was financed. During the last three years I have become a sort of professional beggar, and have had to try to convince people that it would be a good thing to support these flights. Contributions were made, and Sir Charles Wakefield made up the amount at the last moment.

The machine used has quite a history. As you know, about three years ago it flew to Rangoon and back; later it flew to the Cape and back, and then, with floats on, it flew to Australia and back. I do not think any aeroplane ever built has such a record as this, because all these flights were pioneer flights. It is of three-ply construction; I have nothing in favour of three-ply construction, and it may be that metal would be better, but it has experienced every trying condition one can think of, and I think it is just as good, or nearly as good, as it was on the day it was built. When we arrived in Australia no adjustment worth speaking of was required throughout the machine, and I maintain that the reason for that was that it was so well seasoned. Had it been a new machine it would have needed a great deal of adjustment. At Melbourne we opened up the wings, but no adjustment was required, and the fuselage and tail were as sound as a rock. Several parts were worn; probably I knocked it about a bit here and there, and I suppose Ward knocked it about a bit, but otherwise it was O.K.

For this flight we converted the old 'bus into a seaplane by fitting a pair of Short's metal floats, and there is a little history attaching to those floats. First I said I would fly it as a seaplane, then I said I would fly it as an aeroplane, but

it was getting too late for the season and I decided finally to fly it as a seaplane. Unless I could get the floats made and fitted quickly, however, it would be of no use. I telephoned to Messrs. Short's, saying that I wanted to start in a month from that day, and asking how long they would require to make the alterations. They thought they could make them in three weeks. Therefore, I went to their works on the Friday afternoon, the Drawing Office set to work on Saturday morning and finished late on Sunday, having worked throughout the week-end. The men worked day and night on them, and finished in less than three weeks.

I had never flown a seaplane before, and all the seaplane people told me that I should have all sorts of difficulties. I asked them how they learned to fly a seaplane, and they replied that they got into it and said that if others could do it, so could they. I had my own ideas about it, and although Elliott, Ward and Capel knew nothing about seaplanes, we went to Australia and back.

There is nothing to shout about in regard to the petrol supply in this machine; it is quite antiquated. There is a top tank, with gravity feed; the reserve supply is taken from a tube sticking up in the centre of the tank, and when the petrol level is low enough it cuts off and switches over to the bottom supply tank. The top tank holds 55 gallons, and the bottom tank about 100 gallons, so that I had about 150 gallons on board. The petrol is pumped by hand from the bottom to the top tank, and a gauge indicates how much is there. When necessary I pass messages through the window between the cockpit and the cabin.

Spare parts were carried in a big locker beneath my seat, but the spares amounted to nothing very much. If you are going to listen to the engineer with regard to spares you will be carrying a whole machine; he says this and that might be useful, and there is no drawing a line. So we got down to a little insulation tape, some wire, some string (laughter), some grinding-in paste, tools, a spare valve, one or two spare plugs, an odd spring, and things like that. If you are going to carry parts of an engine you might as well not start at all; you have to take it for granted that the engine and the machine will stand up to the job.

There is another point I want to mention. According to the A.I.D., this machine is supposed to carry 4,000 lbs., but that was extended to 4,200 maximum load. Our load, however, with floats, for the flight to Australia was 5,000 lbs., or an overload of 1,000 lbs. It may shock you to hear that, but we got off the water in good style, and the machine handled perfectly. On the Cape flight, I think, the load—although we did not know it—was about 4,600 lbs. Although on the Australian flight the load was 5,000 lbs., I knew the machine would be O.K. provided she was handled quietly, and we had no trouble as the result of the overload, except in getting off sometimes in rough seas.

We come now to the engine, and I will refer to its history. It is the one that took us to the Cape and back, and later to Australia and back. When we started for the Cape we were told that, inasmuch as the engine was air-cooled, and we were to fly through the tropics, we should not get there, but we were successful on that flight, as on the Australian flight. Several improvements were made, but I sat by the engine for 326 hours altogether throughout the flight and she did not falter a single bit. It may not be an engineering proposition, it may be anything you like, but the fact remains that she did not falter all the way, and, from the pilot's point of view, that is all that matters. She made just as many revs. at the end as at the start. The flying time on the outward journey was about 180 hours, and for the return journey about 140 hours. There was no complete overhaul, and the bearings were not touched. The engine had a good top overhaul in Melbourne, where the cylinders were taken off and everything was inspected, but, apart from that, nothing was removed. From England to Australia the valves were not ground in, and on the journey from Australia to England the valves were not ground in again. All that was done on the outward and return journeys was the ordinary every-day maintenance; the plugs were cleaned about

every 10 or 15 hours, the filters were inspected every day, particularly the oil filter, that being the one watching spot to enable us to see if anything was going wrong inside; the machinery was thoroughly looked over, clearances adjusted, and so on, but the cylinders were not removed, except at Melbourne.

With regard to oil temperatures, this being an air-cooled engine, we were told when we started on the Cape flight that we should want an extra big oil radiator. We went to the Cape and back with it, and the difference in the temperature of the oil when it entered the radiator after having been heated up in the engine and when it had passed through the radiator was only 5 degrees. It looked as though the radiator was not doing anything at all, and it was decided to fit a bigger radiator for the next trip. Instead of the temperature difference between the oil entering and leaving the radiator being greater, however, it was reduced to something like 3 degrees with the bigger radiator. Then Mr. Siddeley suggested putting another one on. Therefore, we had one on the top of the engine and one underneath, and the oil went right through the radiator at the top and then through the one underneath, but we found then that there was a difference of only 1 degree between the temperature of the oil entering and leaving the radiators (laughter). The oil goes through the engine at the rate of about 1 gallon every 20 seconds—a terrific rate—and all I can suggest is that it goes through the engine and through the radiator so fast that it has neither time to get hot nor to get cool (laughter). I think that on machine flying in England the temperature of the oil coming out of the engine has been 75 deg., and the temperature of the oil coming out of the radiator has been 35 deg. The highest temperature reached by the oil in this engine throughout the whole journey, in temperatures of 120 deg. in the shade, was 76 deg., and it came out of the radiator at 75 deg. That was at Basra. Therefore, I think the system is a good one, because there is an even temperature of oil the whole time, and there is no sudden change of temperature. I suppose that if the oil went through the engine slowly it might get very hot, and if it went through the radiator slowly it might get very cold.

Coming to the flight itself, we took off from Rochester at 5 a.m. one morning. Many people came to see us off, including my wife, who had travelled during the night from London, though I did not know she was coming. Everybody seemed shocked to hear that I was going to fly right across France in a seaplane, although nobody had seemed shocked on previous flights, when I had flown miles over the sea in an aeroplane with an undercarriage. I would rather come down on the land with a seaplane, with floats, than land on the water with an aeroplane with an undercarriage. In the one case you *are* on the ground, but in the other case you do not know where you are (laughter). I know how I felt about it, and I thought I should get the machine down on the land somehow if necessary.

We pushed out boldly from Hastings—not Folkestone, from where the sea trip is shorter—but from Hastings, with 80 miles of sea before us, although I was a novice in a seaplane. I looked at the big, glassy aerodrome beneath us, and thought that at last I had got down to commercial flying. We got across the Channel, reached the Seine, and followed its course, and I wondered whether or not we should reach Marseilles. I estimated that we should just about reach it on our petrol capacity, so I pushed on past Paris. We consumed about 18 gallons of petrol per hour. It is interesting to note also that the oil consumption was about 4 pints per hour on the outward journey and 3 pints per hour on the return journey. It was very low indeed, but I do not know why there was such a difference. We passed right over France, and completed the 675-mile jump from Rochester to Marseilles. There we landed on a fine big lake at the back of the town, an excellent seaplane base, with an aerodrome alongside. They kept the petrol about two miles away from it—I do not know why, but it is the sort of thing one usually meets with in aviation. We filled up eventually, however,

losing a lot of time we had gained through flying well, and then flew on over the sea to Naples. I have flown round the Mediterranean many times before, hugging that coast-line on an aeroplane, but on this occasion it was a new sensation to push out over the sea, flying between Corsica and Sardinia. We landed at Naples, having covered the distance of 1200 miles from Rochester in a day.

We found the seaplane base on arrival at Naples, and we were told to look out for telegraph wires. Why there should be telegraph wires at a seaplane base I do not know, but I did not see them, and was told afterwards that I missed them by a matter of inches. They were in the way of landing, and I should think they must have been a war-time catch for enemy pilots. One meets with peculiar things in certain branches of aviation. The C.O. there told me that it was the worst seaplane base in the world; he showed me 20ft. thick concrete walls which had been broken when the sea was rough and at a certain angle. Heaven knows what it would do with a seaplane!

From Naples we followed a route across the foot of Italy, right through Greece, through the Aegean Sea, through Alexandretta, along the river Euphrates and on to Basra. I am sure that the only machine in which we can fly over the Mediterranean is a flying boat or a seaplane; it is a flying boat or seaplane job. Flying over the Mediterranean, however, will always be difficult, owing to the bumps caused by the violent down-currents off the mountains if the wind is blowing off the land. The only way to avoid them is to get well out to sea, but if you have to come near to the land the best thing to do is to fly very near to the surface of the water, where evidently the up-pressure counteracts the effect of the down-currents. It can be very bad in the Gulf of Corinth and the Gulf of Patras, on the route to Athens, and where you cannot get away from the land. I have had some very bad bumps; we shall never get over the difficulty, but under those circumstances it is best to fly at about 2ft. above the surface of the water. With an aeroplane, of course, it is not exactly the thing to be done, but with a seaplane it is comparatively safe.

I have always felt that the very good gentlemen of this country to-day who cruise about in big steam yachts do not know what they are missing. Aerial photographs demonstrate that. If they had big flying boats, such as can be built for about a quarter the amount spent on the steam yachts, they would have an entirely different conception of the countries through which they would pass. I can think of nothing more ideal than a luxurious flying boat, upon which the occupants could live and sleep, and I believe that in the future, when the coming generation comes into its own, they will have the aviation sense, or, to use a phrase I have often used, the "aviation mentality." Anyhow, it would be my ambition, if I could afford it, to have a really luxurious flying boat and to cruise the world. I hope to do it very shortly (laughter).

Coming to Alexandretta, I remember that the last occasion on which I went there was when I took Sir Sefton Brancker to Rangoon. We had just come over the Taurus Mountains, and had had a very rough time. They are ghastly mountains, up to 10,000ft. high. We came through a narrow gorge; there was rain and low clouds, and it was like coming through a tunnel. When we got to the bay there was a violent east wind dashing over the mountains, and consequently the air about the bay was in a very disturbed state. We were thrown about in a most violent fashion, and I did not realise how bad it was until I saw Sir Sefton's head hitting the roof, and the luggage hitting the roof. I steered for the open shore, and not too soon, and we landed O.K. I discovered that those sort of conditions exist only for a few months in the year, probably January and February, and possibly December. It was perfectly calm when we arrived on the Australian trip, however, and there is a delightful seaplane base there.

As we got farther east the air became more rarefied. We started on this trip with a metal propeller, which was undoubtedly the right thing to do, but

we had to alter our plans. The propeller was designed for an aeroplane, but we had converted the machine into a seaplane, and could not make another propeller in time. That was all right when the air was dense, as in England, but in the East, although it was the most economical for cruising when once in the air, it was not quite the thing for getting off. Therefore we changed over to a wooden propeller. Undoubtedly metal propellers are the best in the tropics, and we have to get down to them, especially in the case of seaplanes, because neither splashes, rain, nor varying climate hurts them. The wooden propeller we used in the place of the metal one had a better static thrust.

We got off the water at Alexandretta and headed towards Bagdad, passing over Aleppo on the way to the Euphrates. We started from Alexandretta in a temperature well in the sixties (Fahrenheit), and covered about 500 miles in one flight. As we came near to Bagdad in the late afternoon, at a height of about 5,000ft., the temperature was all right, but at 3,000ft. it was getting warm, at 2,000ft. it was hotter, and when we landed it was like going from the cold air of the street into the hottest room of a Turkish bath. Just imagine what will happen in a few years time, when we are taking people to India in four days or to Bagdad in three days, setting out from London on a cold day and arriving in Bagdad three days later in a temperature of 110 degrees in the shade! The problem to be faced is whether the passengers will stand it, so that the medical profession will have to discover how to fortify us against these sudden changes. At any rate, it nearly bowled me over.

From Bagdad we pushed on towards Basra, and I was very glad that on this flight I was on a seaplane. We met a very severe dust storm, which are very prevalent there at that time of the year, and whereas it would have been dangerous to fly on in an aeroplane, it was quite safe in a seaplane, because by hugging the bank of the Euphrates we could land at a minute's notice. As time went on I could not see the bank of the river opposite to that along which I was flying, and eventually, when it got too thick, I decided to land. I landed neatly on the water, taxied up to what looked like a nice soft mud-bank, and drifted on to the beach. We were quite happy, but I imagined what might have been had we been flying an aeroplane. We waited in a police hut until the storm was over, but on the next flight we were caught in more dust storms, which got thicker and thicker. We got over a thick swamp towards Basra, and it was most difficult to fly. I was afraid that the swamp itself would become a thick yellow mass. The water, the land and the atmosphere were all yellow, and unless I had some definite mark I should have no horizon. Therefore it would be too dangerous to keep to the open water, because you all know that under those conditions, or in a thick fog, you lose equilibrium, and I followed the coast line.

Then, while passing over a dry stretch there was a sudden explosion in the cabin. I thought that a Verey light pistol or a rocket had exploded, and realising that that would be dangerous, I asked Elliott if he were on fire. He said "No, but the petrol pipe has burst, and I am hit." I passed a note and a pencil to him, and he wrote that he was losing a lot of blood. I wondered what I had better do. We were flying at about twenty or thirty feet above the desert, it was frightfully hot, and I thought that if I landed there I could not get off again on my own. It was a lonely spot, and I felt that the best thing to do was to race off for Basra. I opened out, therefore—the machine could do about 125 miles an hour—and we raced through the terrific heat to Basra, landing there about 45 minutes later. The weather cleared suddenly as we neared the town. I landed on the Euphrates, ran the machine on to a mud-bank, and when I got into the cabin I discovered Elliott in a terrible condition. He was bleeding very much, and I will mention one little incident to demonstrate what a fine fellow he was. He was a perfect type of what a ground engineer ought to be. He could organise his job, he always thought about it, and stuck to it. As I

lifted him out, with the help of some natives, and lifted him over the edge of the plane, he remembered that in this machine we have to turn the oil off when the engine stops, and he said, "Don't forget to turn the oil off." I got him to hospital, and then awaited news. I think he was in hospital about 1½ hours after the affair. I then began to wonder why a petrol pipe should burst, because there was no pressure behind it. It was the pipe leading from the main tank, and through which the petrol was pumped by hand into the top tank, and I could see no reason why it should burst. A little later two officers inspected the machine, and said that the damage was caused by a bullet. It had pierced the side of the cabin, had gone through the petrol pipe, through Elliott's arm, through his chest, through both lobes of the left lung and into his back. We were flying at such a low altitude that the noise of the firing and the explosion when the bullet hit were simultaneous. You have all heard of the tragedy. The heat did not help matters—the temperature was 110 degrees in the shade—and although he was doing well, he had a relapse and passed away. It was all very sad, and for a while I wanted to give up the flight, for I had been with Elliott for so long, and knew him so well. I received telegrams, however, urging me to go on; they came from my wife, from Sir Sefton Brancker and from Sir Samuel Hoare and others, and I decided to go on. The Air Force said they would willingly lend me a man, and after a search Sergeant Ward was recommended. I saw him, and we set out together. Sergeant Ward had had nothing to do with a Jaguar engine before, but he understood it in theory, and to an engineer one engine is the same as another.

We set out down the river towards Bushire. When we took off at Basra in the morning, at dawn, it was very cool, about 70 degrees. At a height of about 500ft. you come to a belt of hot air, which becomes hotter and hotter until an altitude of about 5,000ft. is reached. That hot belt of air hangs about all through the night. We passed through it successfully, and pushed on down the Persian Gulf towards Bushire, where we were rather lucky in one sense and unlucky in another. It was a hot day, and there was a very heavy mist, and we found it much cooler in the mist than above it. The mist was so heavy that, twenty minutes before we got there, a pinnace from a ship at anchor three miles out had lost itself, and could not find its way in. The seaplane base there was not a bad one, though there was a fairly strong current.

There is something very interesting about flying in the East. On half-throttle we could cruise at 100 miles an hour in north-west Europe, but on the Persian Gulf we cruised at about 80 miles an hour on half-throttle, and in addition to losing air speed owing to the rarefied atmosphere, we lost ground speed too. I was told that I should open out a little more, but if I did that I should use more petrol, I am sure. In theory, I know, one should open out, and should not thereby use any more petrol or put a greater load on the engine, but from my experience I think that does happen. Therefore, flying in the Persian Gulf will not be quite so economical as flying in Europe. When running an air line, however, and flying on 365 days in the year, day or night—at least that ought to be done—regularity would tend to eliminate many of the costs and so reduce running costs. Possibly that may make up for the extra cost of running a machine of higher power there as compared with a lower power machine, with less regularity, in Europe. Perhaps those who understand these matters better than I do can solve the difficulty, but that is how I found it.

After showing some aerial photographs of rock formation along the coast of the Persian Gulf, Sir Alan continued:—I discovered that the Persian Gulf is not very good for seaplanes. A seaplane is not very good in a rough sea, especially when there are rollers, and in the Persian Gulf there appear to be rollers permanently, whether the sea is rough or whether it is calm. In addition, the rollers are across the wind; the crests of the waves are one way, and the rollers the other, which makes it very awkward indeed. There should be many very fine seaplane bases, however, although we had not to pick them.

We landed in a very rough sea, and it was extremely difficult to get away four days later. We tried to get away by bouncing over the breakers. The people there told us that as far away as we could see from the shore they were O.K. They were O.K. close in, and we could ride the smaller ones, but then we came to the big ones, and I can assure you that taking off in a seaplane in big breakers is no joke. We had some very trying moments, and it is marvellous how the floats stand the thuds. The engine and the propeller got covered in water; at one time we were at 45 degrees into a wave, and then 45 degrees into the air, and we found that we had a bent strut. I discovered, however, that Ward was a good blacksmith; he was a tool-maker by trade, and could do most things. Some years ago a flight was made to Australia in a Handley-Page machine, and spares had been put down—as a matter of fact there were enough parts to build a machine. These spares had lain there for many years, carefully looked after by successive British Consuls, checked, counted and so on, and we found a centre section strut. It was pointed out to me that the spares were for a Handley-Page machine, and they asked what would happen if such a machine went through there. I replied, however, that the type of machine for which they were made was obsolete six years ago. The strut was hammered out by Ward, who was working in the heat of the sun, stripped to the waist, and was assisted by four natives—he is a wonderful fellow with natives—and it fitted dead tight, to a thousandth of an inch. It was a perfect splice, and it took us all the way to Australia and back.

I might mention that the undercarriage on the floats had no shock-absorbers at all; the floats were canoe-shaped. I think we did very well, therefore, although I have heard that they might have been improved if we had had a shock-absorber on the rear strut.

We continued down the Gulf towards Karachi. That is going to be the terminus of the new Imperial Airways route from Cairo to Karachi, which should commence running next January, and I think they will have every success from the start. In my view they will find it much easier than flying from London to Paris. They may encounter dust storms, and so on, but they will have no fogs; they will always be able to see more or less where they are flying, except in dust storms, and that will tend towards regularity, and, apart from the fact that the pilots will be living a long way from home, I think most of them will look upon it as a rest cure.

From Karachi we went up the Indus, about 500 miles, in a dust storm, and landed at Bahawalpur, then 400 miles overland towards Delhi, and down to Allahabad. The landing at Delhi was all right, but the getting off was bad, and I understand that in the dry season there would not be enough water. We had ten-knot currents, and although a seaplane is perfect for manipulating in the air and for landing and taking off, it is a different matter altogether when it is on the water. So long as the propeller is moving you are going somewhere, and when you are on a river and the propeller is not moving you are also going somewhere, but nobody seems to have much control, especially in a ten-knot current, and we had extreme difficulty. I do not think that sufficient attention has been paid in the past to the little details connected with mooring. You have a hook and a line, and grab the buoy as well as you can. I have heaps of ideas on the subject, and I feel that lots can be done in connection with these incidental things to ease the difficulties that engineers and pilots have to cope with on the water. With a flying boat the proposition is simpler. In that case you are in the front of the engine, and you can get to the buoy and moor up straight away, but when you have to stand behind the propeller, and get up to within a few inches of the buoy, and have to ensure that the pull is direct on the front when you are moored up, and not at the side, it is not so simple. It was not until about the last three landings on the homeward journey that we ever worked according to plan. The whole of the organisation for the flight had to be put

down through the medium of correspondence; nobody knew anything about seaplanes until we arrived, and we had to depend entirely on the people at these places to do as we asked them. When we arrived at Allahabad we found six buoys, and each was big enough to hold a battleship, whereas I had asked for a petrol can with a hook on it (laughter). The presence of so many people in boats also caused a little difficulty.

At Calcutta we landed on the Hoogli. Calcutta should be the starting-point of one of the greatest flying boat or seaplane routes in the world, in my opinion, namely, from Calcutta to Singapore. By that means we could open up vast tracts of country in Burma and Malay, which need communications at the present moment. In this connection I should like to express the view that there is too much talk about making air lines pay as transport propositions. I think we should look upon air lines in these parts of the world as a means of opening up and developing the countries concerned. We put down a railway, and it does not pay as such, but it builds up the country, and therefore it is worth while. That is the way we should consider air lines.

Before I left England I was told that I was wrong in making the journey on a seaplane rather than an aeroplane, but I stuck to my point, and held that the only way to make the journey was by seaplane, because we would be travelling in the monsoon period, which was the worst part of the year. Whereas the rainfall in England was 30 inches, it was 300 inches there, and all in four months —the four months in which we were travelling. We went in the worst period of the year, in order that the survey should be a sound one. At Akyab we found a fine seaplane base when I flew to Rangoon with Sir Sefton Brancker. It is very useful, for we can land in the wind, no matter what the direction, there is very little current, and the water is calm.

Within four miles of Rangoon we ran into the heaviest rain we ever tackled on the outward journey; we had to turn back and circle round, and at last landed on a creek. We waited until the rain had passed over, and then got back to Rangoon. If we had not used a seaplane the flight would have been washed out exactly five times. We should have been caught out because it is impossible to land with an aeroplane from the moment we leave Calcutta until we reach Australia on anything other than an organised or prepared landing ground. It follows, therefore, that as we could not get to our destinations on many occasions the flight would have been washed out. With the seaplane, however, we were able to get through. The insurance people were up against the seaplane, and pushed the rate up. I pointed out that I was using a seaplane in order to cut down the risk, and therefore the premium should be less, but they would not hear of it. I am not grumbling, because I have proved the point, but the insurance people were not very grateful. The rate was just over ten per cent., and it is interesting to note that it was just the same as would have been charged to a sailing ship 100 years ago.

The picture of the Burma coastline will give you an idea of the nature of the country, and it only needs an air route there to open up the country. Heaps of people would go there at the present moment, but they would be so isolated. Men will not contemplate putting down rubber plantations in such a place, but if there were an air route there, so that they could be in communication once or twice a week, it would be a different proposition altogether.

We landed at Singapore in what would make an ideal seaplane base. We did not stay very long, but pushed on along the Sumatra coastline. The country consists of lonely swamp jungle. We pushed along the Java coastline towards Australia, and were having delightful weather there, on the other side of the equator. Then we got to Bima. The monsoon period there occurs at about the present time of the year, but I do not think it is nearly so bad as the monsoon period further north, in Burma. The Dutch are very much alive to the value

of aviation, and talk about air lines. I do not know whether they will operate them soon.

The sea in these parts is so clear that you can see the bed, and I have taken a photograph of the ocean bed through about five fathoms of water, and from a height of 1,000ft. above the surface of the water. The water is so clear that you cannot see the surface, and the crest of a wave running across it gives the impression of having thrown a bucket of water on to glass. Landing on the water is very dangerous, therefore.

At Kupang the Dutch authorities looked after us very well, and we set off from there for the flight to Australia, a distance of 500 or 600 miles, of which 500 miles was open sea. I worked on a compass course, and my compass was a Periodic—the best I could have. Sailors were surprised to find that I had set out from London using the same compass all the way, but there was no soft iron on board, and no local magnetism. Our departure was wirelessed to Darwin, and we gave our bearing. I took the bearing from one place at Kupang, and they thought I had taken it from another, and consequently they were worried because the latter would bring me out at about Melville Island. They were still more worried when I had not arrived after a flight of about 4½ hours. This was due to a head wind. We went on and on, and presently felt we ought to see the coastline in about half an hour; then we thought we did see it, but were mistaken. When we did see it at last we were relieved, and we found that, after this long sea journey, by compass, we had hit our objective to within five miles.

In Australia we received every possible assistance; every man jack did all he could, and I do not know what we should have done without them. At Darwin the floats were taken off, and we converted the machine into a land machine. There was hardly any sign of corrosion on the floats, although from time to time the paint did come off the bottoms of them; in fact, I got rather tired of painting floats, which seemed to be my pet job. We must get down to finding a paint which will not come off under these conditions. I was told, before I started, that I should not do the journey with those floats, but we used them on the outward and return journey and they were as good as new afterwards.

Many people came to Darwin to meet us, including the Director of Civil Aviation, who travelled 2,200 miles for that purpose—a greater distance than from Constantinople to London. Before leaving Port Darwin we visited the spot at which the late Sir Ross Smith crossed the coast on his first flight from England to Australia. That was a very magnificent effort, considering how many years ago it was made, and considering the state of aviation at that time. Another six years' experience intervened before we accomplished our flight. A very fine monument is erected at the spot at which Sir Ross Smith crossed the coastline.

There is no country in the world like Australia for flying; indeed, Australia was made for aviation, for there are no fogs, no gales and no blizzards, and the conditions are perfect. One rainy day they thought I would not fly; visibility was very bad, they said, but one could see for six or seven miles. The thing that is holding Australia back to-day is the isolation question. You cannot get a man to go out into the back country, and take a girl with him, if they are to be isolated for weeks and months at a time, but aeroplanes will bring them into close touch with townships and railheads. I think the owners of private aeroplanes in Australia will alter the whole scheme of things. There are already three or four very fine air lines in Australia.

At Sydney we were welcomed by a large crowd. From there we flew on to Melbourne, and our welcome there indicates the sudden interest that Australia has taken in aviation. They realise what aviation is going to do for their country; it will do more for Australia than it ever can do for this country. I think three Air Clubs were formed while we were there; the membership filled

up, and they are going forward at once. There was great enthusiasm at Melbourne, and the crowd was such that I do not know how it was that nobody was killed. I was taken out of the machine by four policemen, put into a hangar, and smuggled away later in a car.

We passed through the centre of Australia and back towards Darwin. We landed on one occasion in the heart of the country, where a man had a broken-down car. It would have been broken down for six months, but he sent a telegram asking me to take him a spare part, and he was delayed for about a week only, instead of six months. That demonstrates what aeroplanes can do for Australia.

While at Melbourne I took on board one named Capel. We were going to try to make a dash home, and I knew that that would mean too much for Ward to do. There would be enough for two, and therefore we added to our load. At Port Darwin we re-fitted the floats and skimmed the machine down a bit to lighten it, but I was a little doubtful.

We landed at Bima and got along in fine style, and I think we should have reached home in a little over a fortnight but for the fact that we collided with a big storm just north of Sumatra. Sumatra sheltered the coastline from the monsoon. It was the worst storm that year, and we could not fly through it, and had to land on a lonely island. We beached the machine on the leeward side, and took refuge there. The wind was blowing down from the mountains, and we took off in a cross wind, almost a down wind. We kept bumping over the rollers, but we got into the air eventually, but were caught out again owing to very heavy rain, which tore the fabric from the propeller. I knew of a point of refuge at Tanoon, however, where we put down. At Tanoon there was a sheltered creek which I had noticed on the outward journey. While we were there we discovered a bent strut, due to taking off over rollers on the leeward side of the lonely island. We had not any Handley-Page spares, but we found an old Ford chassis, and with this Ward made a good splice, almost as good as that made previously. Later the rain held off a little, and we got to Victoria Point. I should mention, however, that when we had landed on the beach in the lonely island we had knocked a small hole in the float, but we dug a hole in the beach in order to get beneath it, and mended it.

At Victoria Point we experienced the worst rain I had ever seen. We could not see ten yards ahead, and we had to fly back, but if we had been half a day nearer home we should possibly have completed the journey from Australia to England in about sixteen days. However, I think it was a good thing we met that bad weather, because otherwise we should have had a wrong impression of what a monsoon could do. We now know what we are up against when trying to fly continually through the monsoons. We had no wireless communication and no weather reports; in fact, nobody there could tell us anything about the weather.

We pushed off later in fair weather, and I flew the 400 to Rangoon. We got back across India to Karachi without much trouble. At Basra the heat was terrific, anything up to 110 degrees in the shade. The engine had done about 20,000 miles without a complete overhaul, and it was here that the oil temperature rose to its highest point, namely, 76°C. Also, we were flying in the middle of the day; the Air Force does not usually do that at that time of the year.

We passed on to Bagdad, Alexandretta, then to the Isle of Leros—a delightful base in the Ægean Sea—and then to Athens, where we spent the night with our friends of the Blackburn Co., who looked after us well. Then we came on through Marseilles, through France, over the Channel, crossing the English coast at Hastings. From there we went to Short's, our starting-point, and then through a piece of good old fog up the Thames, and came out of it again at the Tower Bridge. The river looks a terrible little ditch from the air, and it seems

that one can never get down into it. The wind was blowing off the Houses of Parliament, and it was rather difficult to land; I had to circle once or twice before I thought about coming down. I do not think that part of the river would make a seaplane base; it would be better further up the river. (Laughter.) You will notice that in landing I am rather fond of getting the tail down.

Colonel THE MASTER OF SEMPILL, A.F.C. (Chairman of the Society), proposing a vote of thanks to Sir Alan Cobham, said:—I think you will all agree that Sir Alan has taken us with him on this wonderful flight; we have enjoyed its many beauties, and have experienced many difficulties. We have been through dust storms and monsoons, and I feel almost that we must now get thoroughly dry and tidy ourselves up. Before doing that, however, I will ask you to accord a most cordial vote of thanks to Sir Alan for his admirable address, and to wish him every success in any other similar venture he may undertake in the future.

The vote of thanks was accorded with enthusiasm.

THE ROYAL AERONAUTICAL SOCIETY AND THE INSTITUTION OF AUTOMOBILE ENGINEERS

A joint meeting was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, November 4, 1926. The Master of Sempill was in the chair.

The CHAIRMAN, in opening the meeting, said: This is the third occasion on which the Institution of Automobile Engineers and the Royal Aeronautical Society have met together jointly, and the two occasions last year were so successful and resulted in such good discussions that both the societies decided to perpetuate the joint meetings this year, and I hope this will be a permanent yearly arrangement. The author of the paper to-night is Mr. Mucklow, who is a lecturer in Mechanical Engineering at the Manchester University. Before that he was, of course, like most of us, engaged in the war, but prior to that he was at the McGill University. Those of us who have seen an advance copy of the paper will, I am sure, realise the enormous amount of work it has involved. I will now ask Mr. Mucklow to read his paper.

THE EFFECT OF REDUCED INTAKE-AIR PRESSURE AND OF HYDROGEN ON THE PERFORMANCE OF A SOLID INJECTION OIL ENGINE

BY G. F. MUCKLOW, M.SC.

(ASSOCIATE MEMBER OF THE INSTITUTE OF AUTOMOBILE ENGINEERS).

HYDROGEN

1 Summary

(*a*) *Introductory.*—The paper deals with experiments carried out in the engineering laboratories of the University of Manchester on a Crossley solid-injection oil engine in which small quantities of hydrogen or coal gas were introduced along with the air supply to the engine.

(*b*) *Range of Investigation.*—Three series of trials were run with hydrogen, each at a different load, namely, 53.4, 39.4, and 24.4 b.h.p. The maximum amount of hydrogen used was slightly more than 3 per cent. by volume of the air supply, corresponding, at the lightest load, to some 14 per cent. by weight of the oil fuel supply.

Three corresponding series of trials were run using coal gas in place of hydrogen, the maximum volume of gas employed being 5 per cent. of the air supply. At the lightest load this corresponds to approximately 2.4 times the weight of fuel oil used.

(*c*) *Conclusions.*—Such quantities of hydrogen or coal gas can be used satisfactorily in the type of engine considered. No trouble was experienced due to pre-ignition or other causes, and the engine appeared to run more sweetly when gas was being used.

When running at constant load and speed, the admission of small quantities of gas appears to cause combustion to take place at a slower rate, giving a lower

maximum pressure and more burning down the expansion stroke. The thermal efficiency is in consequence slightly reduced, while the heat-losses to exhaust are increased.

2 *Introduction*

In an airship in flight, as the supply of oil fuel is consumed, a corresponding amount of hydrogen must be released, and it thus becomes of importance to determine whether this waste hydrogen may be utilised to replace a portion of the oil fuel supplied to the engines.

The object of the experiments was to ascertain the effects of the admission of small quantities of hydrogen during the suction stroke, in the case of a heavy-oil engine of the solid-injection type.

Before dealing with the results it is well to record previous information bearing on the subject.

A series of experiments by Ricardo,* in which hydrogen was used alone and with petrol in a variable-compression engine, showed that by using a small priming charge of hydrogen very weak petrol-air mixtures could be burned efficiently, and that the high efficiency at light loads and other advantages of a low-temperature cycle could thus be attained.

In trials with hydrogen alone, at a compression-ratio of 7 : 1 detonation and pre-ignition occurred when using a higher gas/air ratio by volume than approximately 20 per cent., whilst the smallest gas/air ratio used appears to have been approximately 11 per cent., at which figure the indicated thermal efficiency was much reduced.

In two series at a compression-ratio of 5.45 : 1 in which hydrogen and petrol were used together, the supply of petrol was varied, while the amount of hydrogen remained approximately constant, the ratio by volume of gas/air being about 11 per cent. for one series, and 6 per cent. for the other.

In all three series of trials, as the mixture strength was reduced below that possible with petrol alone, the indicated thermal efficiency rose, until a point was reached when further reduction in mixture strength caused the efficiency to fall, presumably owing to slow burning.

It has been suggested, probably largely because of the results of these experiments, that the effect of an admixture of hydrogen with the air supply to a heavy-oil engine of the " semi-Diesel " type would be to accelerate combustion and thereby to increase the efficiency of operation.

The physical factors involved are, however, essentially different in the two cases. In the case of a petrol engine, the advantages to be gained by the use of hydrogen are mainly due to the fact that whereas no ordinary mixture will burn sufficiently rapidly if weakened more than about 15 per cent. below the mixture strength required for complete combustion, the use of small amounts of hydrogen permits of a far wider range of weak mixtures being used at light loads. Thus the use of hydrogen as a priming charge permits of the advantages of a low-temperature cycle being realised.

When the above results are considered with a view to the use of hydrogen in a solid-injection heavy-oil engine, it will be seen that the chief advantage offered by the use of hydrogen is nullified at the outset, since with this type of engine the " mixture strength " may be weakened indefinitely without the use of hydrogen, and in consequence the advantages of the low-temperature cycle at light loads are already present to a great extent.

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* See Report of the Empire Motor Fuels Committee, *Proc. I.A.E.*, Vol. XVIII., Part I., p. 333 *et seq.*

Thus it does not appear likely that any such increase in efficiency will follow the use of hydrogen in the solid-injection oil engine. Furthermore, it will be seen that if pre-ignition and detonation are to be avoided in such an engine, only comparatively small amounts of hydrogen may be used. In the oil engine under discussion the compression-ratio is 10.3 : 1, giving a compression-pressure and temperature of the order of 310 lbs. per sq. in. and 1000°F. respectively. From Ricardo's experiments it appears that a mixture of approximately 20 per cent. by volume of hydrogen in air pre-ignites, in a petrol engine, at a compression-ratio of 7 : 1. Information kindly supplied by Professor H. B. Dixon, F.R.S., from the results of experiments with an adiabatic-compression machine, showed that at a compression-ratio of 10.6 : 1, giving a temperature of 878°F., a 9.4 per cent. by volume mixture of hydrogen and air exploded, whilst with a 5 per cent. mixture at a compression-ratio of 12.25 : 1 and a compression-temperature of 961°F. no explosion occurred. It thus seems likely that the maximum amount of hydrogen which could be used in the present oil engine without pre-ignition is in the neighbourhood of 5 or 6 per cent. by volume of the air supply.

In closed-vessel explosion experiments by R. W. Fenning* the effect of the addition of 2.47 volumes of hydrogen to 100 volumes of a 9.13 : 1 air/benzene mixture is mentioned. Two indicator diagrams are shown, one without and one with hydrogen, the initial temperature and pressure being in each case 300°C. and 102 lbs. per sq. in. It is seen from these diagrams that the time from the passage of the spark to the attainment of maximum pressure is very nearly doubled by the addition of the hydrogen.

In the same paper reference is made to experiments by Professor Riedler in the following terms :—

" In experiments with mechanically-hydrogenised benzol, Riedler found that tests with unmixed and mechanically-hydrogenised benzol showed that the engine output with the latter decreased approximately in proportion to the amount of H_2 introduced, while the fuel consumption increased in a yet higher ratio. Further, the addition of H_2 caused irregularities in combustion ; in particular, it appeared to delay combustion, causing long visible flames to issue from the exhaust, and with normal mixtures sooting took place."

These results are also in accordance with the results of the work of Messrs. Wollers and Ehencke, of the Krupp Research Laboratories, who conclude that :—

" On injection a liquid fuel immediately vapourises. Under the influence of the high-compression temperature the fuel molecules decompose, the freed valencies immediately taking up oxygen. The ease with which the oxygen is taken up will depend upon the nature of the valencies set free—in other words, on the constitution of the fuel. The formation of the free valency and ignition and burning are simultaneous ; there is no intermediate formation of free hydrogen to act as an igniter, as was thought by Neumann."

3 *Apparatus*

(*a*) *Engine.*—The engine used during the investigation was a single-cylinder Crossley solid-injection heavy-oil engine, Type 0123. The bore and stroke are 14 and 23 in. respectively, whilst the clearance volume is 378.5 cu. in., giving a compression-ratio of 10.3 : 1. The normal speed is 211 revs. per minute, and the maker's rating 66 b.h.p.

In this type of engine the oil is injected into the cylinder through a sprayer mounted in the side of the cylinder head. A cam-operated plunger pump delivers the fuel to a copper pipe connected to the sprayer, the pressure of oil lifting a needle-valve in the nozzle against the action of a spring. A by-pass valve is

* See Aeronautical Research Committee Reports, 979, May, 1924.

fitted on the pump outlet, and is controlled by the centrifugal governor. The compression-pressure is in the neighbourhood of 310 lbs. per sq. in. absolute, the heat of compression being relied on to fire the charge.

During the trials under review the fuel pump was timed so that it commenced to deliver oil to the sprayer 21 degrees before top dead-centre. The valve timing diagram was as shown in Fig. 1.

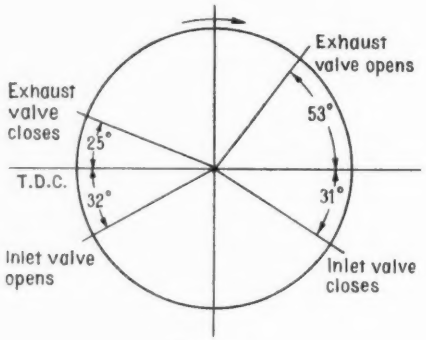


FIG. 1.
Valve Timing Diagram.

(*b*) *Indicators.*—It is to be noted that the time at which the needle-valve of the sprayer lifts is not positively controlled. For reasons referred to later it was found desirable to arrange an indicator to show the exact point at which the fuel charge was injected.

In order to effect this, a contact-breaker was arranged on the sprayer, so that the lifting of the needle-valve broke the primary circuit in an induction coil, causing a spark to puncture the paper carried by a drum which was oscillated 90 degrees out of phase with the piston of the engine. A second contact-breaker was arranged to be operated by the flywheel so that the primary circuit was broken and a puncture produced on the paper at 90 and 270 degrees crank angle. By this means the exact point at which the needle-valve lifted could be determined.

For the examination of combustion, a Hopkinson optical indicator was used, the reciprocating motion being set 90 degrees out of phase with the piston of the engine. No normal-phase indicator diagrams were taken, as it did not appear that any information of importnce was to be obtained from these.

A Bowden cable was used to connect the indicator to the reciprocating motion, the cable passing over one pulley mounted on a ball bearing. Every endeavour was made to obtain rigidity in the mounting of the indicator and its drive.

The phase-setting of the indicator was checked directly against the engine crank angle by the following method. The engine flywheel was marked off in degrees, and the engine was barred round, the flywheel being moved two degrees at a time. After each movement the indicator switch was operated and a spot produced on the photographic plate. The plate, after being developed, was magnified to $2\frac{1}{2}$ times its original size, and the points were transferred to paper. The distance between the points was then carefully measured, and, from the mean of several diagrams, a curve was prepared giving a comparison between the displacement of the spot of light on the indicator diagram and the engine crank angle. This curve was then used in the examination of all diagrams, though the divergence of the curve from the theoretical was extremely small.

The phase-setting of the "Spark Indicator" was checked in a similar manner, and a curve of displacement obtained.

(*c*) *Air Supply.*—The air supply to the engine was measured by means of an air box, 5ft. by 4ft. by 8ft. Four two-inch diameter orifices were employed, the amount of air passing being deduced by the use of the coefficients given by Watson.* In order to reduce the variations of pressure in the box an expanding leather bellows, 3ft. 6in. long by 1ft. 6in. diameter, was fitted between the air box and the engine.

(*d*) *Gas Supply.*—The supply of coal gas was drawn from the town main, and passed through a meter to a one-inch bore pipe connected to the air-intake pipe of the engine at a point about one foot distant from the inlet valve.

In the case of hydrogen, a battery of cylinders was coupled up to a fine needle-valve controlling the admission of the gas to the meter. The needle-valve was regulated by hand, so as to maintain a constant pressure in the meter, and the gas then passed to the engine through the one-inch bore pipe mentioned above.

In the experiments, the valve was regulated so as to supply the gas to the intake pipe at the required rate, while the governor automatically adjusted the supply of fuel oil to the sprayer, so as to keep the speed constant.

(*e*) *Fuel.*—The fuel oil used was "Anglo-American Diesel Oil," the analysis by weight being—

H.	... ...	12.9 per cent.
C.	... ...	85.8 ,,

The higher calorific value, as determined by the Mahler Cook Bomb Calorimeter, was 20,440 B.Th.U.'s per lb., corresponding to a lower calorific value of 19,215 B.Th.U.'s per lb.

The analysis of the coal gas used was made with a Bone and Wheeler Apparatus, the mean results being :—

Percentage by volume	CO_2	6.06
	O_2	0.76
	CO	14.36
	CH_4	21.30
	H_2	35.92
	N_2	21.60

The calorific value of the coal gas as determined by a "Boys" Calorimeter was :

Higher	... 440.1 B.Th.U.'s per cu. ft. at 760 mm. Hg. and 15°C.
Lower	... 408.3 B.Th.U.'s per cu. ft.

The density of hydrogen was taken as 0.005299 lbs. per cu. ft. at 760 mm. Hg. and 15°C., and the calorific values used for hydrogen were :—

Higher	.....61,500 B.Th.U.'s per lb.
Lower	..... 52,800 ,, ,,

4 *Range of Investigation*

Two sets of trials were run, one with coal gas and one with hydrogen.

As it was thought possible that there might be trouble through detonation when hydrogen was being used, coal gas was first employed. Three series of trials were run, each being characterised by a different load, approximately 54, 39 and 25 b.h.p. respectively. The speed of the engine was maintained sensibly constant throughout, and care was taken to ensure that the jacket-water-outlet temperatures were also sensibly the same in all tests.

* See *Proc. I. Mech. E.*, May, 1912.

In each series tests were run with varying amounts of coal gas, the maximum amount of gas being in the neighbourhood of 5 per cent. by volume of the air supply. At the lightest load employed this amount of gas corresponds to approximately 2.4 times the weight of fuel oil supplied.

After the trials with coal gas had been concluded, a corresponding set of three series of trials was run using hydrogen. The maximum amount of hydrogen admitted was slightly over 3 per cent. by volume of the air supply. At the lightest load used, the corresponding weight of hydrogen is about 14 per cent. of the weight of fuel oil used.

In each trial two 90-degree advanced diagrams were taken with the optical indicator, whilst observations of brake horse-power and consumption of air, gas and fuel oil were recorded.

The general particulars of the trials run are shown in Table I.

TABLE I.

	Series.	Mean speed.	Mean B.H.P.	Mean B.M.E.P.	Max. amount of gas used. Percentage by volume of air supply.	Max. amount of gas used. Percentage by weight of fuel oil.
Set No. 1	G & F	213.7	54.0	56.5	5.0	147
Coal Gas.	H	214.1	39.5	41.3	4.8	183
	J	215.0	24.6	25.6	4.5	239
Set No. 2	L	213.4	53.4	56.0	2.65	6.3
Hydrogen.	R	214.3	39.4	41.2	3.08	10.3
	Q	215.1	24.4	25.4	3.04	14.2

5 *Experimental Results*

(*a*) *General.*—No ill-effects of any kind ensued from the use of gas, nor were any indications of pre-ignition or detonation experienced, and it was found that when any appreciable quantity of either coal gas or hydrogen was being admitted, the engine appeared to run more sweetly.

At any particular load, as more gas is introduced, the supply of fuel oil is automatically diminished, and it appeared that there might be some variation in the timing of the lifting of the sprayer needle-valve due to this cause. It seemed important to settle this point, since any variation in the timing of the injection would in all probability produce effects which would mask the true effect of the gas admitted.

To clear up this point, the "Spark Indicator" previously mentioned was devised, and observations were taken of the needle-valve action when injecting widely different quantities of fuel.

The results are shown in Fig. 4, and indicate that the quantity of fuel injected has no effect on the point in the stroke at which the needle lifts.

It will be noticed that whereas the fuel pump commences to operate at an engine crank angle of 339 degrees, the needle-valve does not leave its seat till some nine degrees later.

(*b*) *Thermal Efficiency.*—The effects of the admission of coal gas or hydrogen are shown in Figs. 2 and 3 and Table II.

Effect of Hydrogen.—At all loads, the admission of hydrogen causes a slight reduction in the brake thermal efficiency. The rate of decrease in efficiency as the ratio weight of hydrogen/weight of fuel oil is increased, is roughly independent of the load on the engine.

Effect of Coal Gas.—In the case of coal gas, at any given load the fall in efficiency appears to be directly proportional to the ratio weight of coal gas/weight of fuel oil, whilst the rate of decrease in efficiency becomes more rapid as the load on the engine is reduced.

It will be observed that whilst at the highest load dealt with the admission of a given volume of hydrogen produces a greater fall in efficiency than the

admission of the same volume of coal gas, at the lowest load, approximately the same effect is produced by either hydrogen or coal gas.

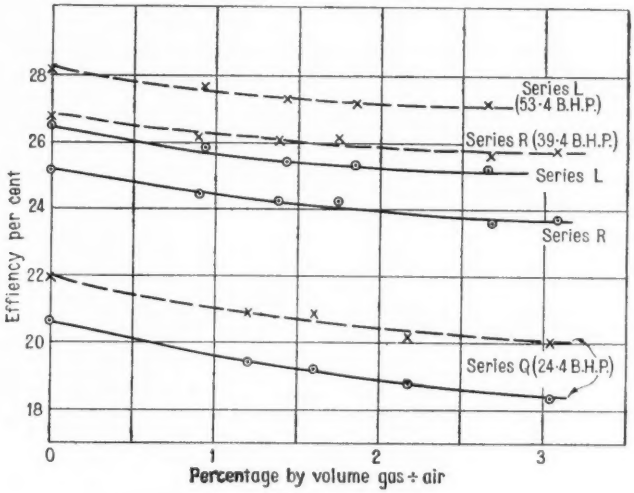


FIG. 2.

Brake thermal efficiency with hydrogen.

——— *on higher calorific value.* — — — — *on lower calorific value.*

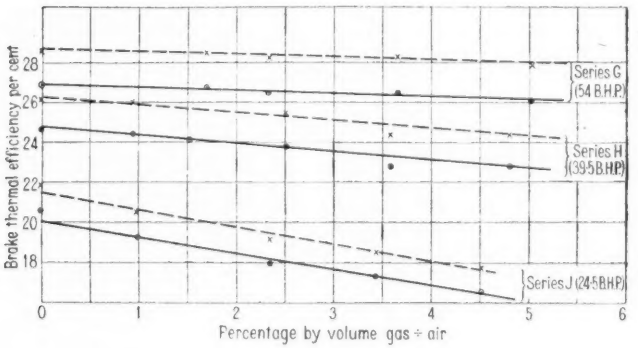


FIG. 3.

Brake thermal efficiency with coal gas.

——— *on higher calorific value.* — — — — *on lower calorific value.*

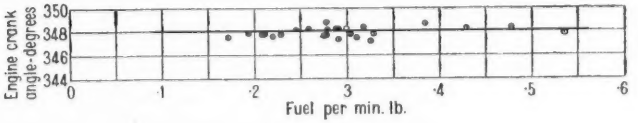


FIG. 4.

Point at which sprayer needle lifts.

(*c*) *Heat-Losses.*—No attempt was made to measure the heat-losses to the cylinder walls during the trials under consideration, although the outlet temperature of the cooling water was maintained as far as possible constant.

The heat rejected in the exhaust gases was, however, measured, an exhaust calorimeter of the spray type being used. The temperature of the exhaust gases was measured by means of a mercury thermometer inserted in a pocket in the exhaust pipe at a point close up to the breech. It is realised that the temperatures thus measured can give but a rough idea of the actual temperatures of the gases at the end of expansion, and the readings thus obtained are of service from a comparative point of view only.

TABLE II.

	Series.	Gas/Air Ratio percentage by volume.	Gas/Fuel Oil Ratio percentage by weight.	Brake Thermal Efficiency. Higher C.V.	Brake Thermal Efficiency. Lower C.V.	Reduction in efficiency (on Higher C.V.) as a percentage of normal efficiency.
Hydrogen.	L	—	—	26.5	28.1	—
	(53.4 B.H.P.)	0.93	2.0	25.8	27.6	2.4
		1.43	3.1	25.4	27.3	3.9
		1.84	4.2	25.3	27.2	4.3
		2.65	6.3	25.2	27.2	4.8
	R	—	—	25.1	26.7	—
	(39.4 B.H.P.)	0.90	2.6	24.4	26.2	2.7
		1.38	4.1	24.2	26.0	3.5
		1.75	5.4	24.2	26.1	3.5
		2.68	8.6	23.6	25.6	6.1
		3.08	10.3	23.7	25.7	5.7
	Q	—	—	20.6	22.0	—
	(24.4 B.H.P.)	1.20	4.8	19.4	20.9	5.9
		1.61	6.7	19.3	20.8	6.7
		2.17	9.4	18.8	20.4	9.0
		3.04	14.2	18.4	20.1	11.0
Coal Gas.	G & F	—	—	26.9	28.6	—
	(54 B.H.P.)	1.71	36.6	26.8	28.5	0.4
		2.34	52.7	26.6	28.3	1.3
		3.67	92.9	26.5	28.4	1.3
		5.03	147.0	26.2	28.0	2.8
	H	—	—	24.6	26.2	—
	(39.5 B.H.P.)	0.95	24.4	24.4	26.0	0.8
		1.53	45.8	24.2	25.8	1.9
		2.52	75.8	23.8	25.4	3.3
		3.60	117.7	22.9	24.4	7.1
		4.82	182.9	22.9	24.5	7.1
	J	—	—	20.6	21.9	—
	(24.6 B.H.P.)	1.00	35.14	19.2	20.6	6.7
		2.36	91.9	18.0	19.2	12.7
		3.45	156.7	17.4	18.6	15.6
		4.53	238.6	16.6	17.8	19.3

The accuracy of these figures given for the heat-losses to exhaust is, of course, impaired by the fact that an unknown quantity of the heat which should appear in the gases is passed to the exhaust valve, combustion head, etc.

It will be seen from Table III. that, as the amount of gas is increased, the exhaust temperature rises in all cases. The rate of increase in exhaust temperature, as the ratio gas/air by volume is increased, is approximately the same at all loads, and is, moreover, unaltered whether coal gas or hydrogen is being admitted. Thus each one per cent. increase in the ratio by volume of gas/air causes a rise of approximately 10°F. in the exhaust gas temperature.

TABLE III.

Series.	Gas/Air Ratio percentage by volume.	Gas/Air Ratio percentage by weight.	Measured exhaust temperature F.	B.Th.Us. per min. in exhaust gas.	Percentage of heat in fuel appearing in exhaust.
G & F	—	—	676	3000	35.2
54 B.H.P.	1.71	36.6	687	3263	38.4
(Coal Gas)	2.34	52.7	692	3456	40.4
	3.67	92.9	705	3444	39.6
	5.03	147.0	718	3560	40.4
H	—	—	562	2698	39.8
39.5 B.H.P.	0.95	24.4	578	2844	41.5
(Coal Gas)	1.53	45.8	585	3097	44.7
	2.52	75.8	596	3182	45.2
	3.60	117.7	613	3264	44.4
	4.82	182.9	626	3301	44.7
J	—	—	462	2099	41.6
24.6 B.H.P.	1.00	35.14	473	2344	43.2
(Coal Gas)	2.36	91.9	486	2541	43.9
	3.45	156.7	494	2604	43.4
	4.53	238.6	502	2750	43.9
L	—	—	682		
53.4 B.H.P.	0.93	2.0	701		
(Hydrogen)	1.43	3.1	710		
	1.84	4.2	712		
	2.65	6.3	716		
R	—	—	553		
39.4 B.H.P.	0.90	2.6	562		
(Hydrogen)	1.38	4.1	567		
	1.75	5.4	570		
	2.68	8.6	571		
	3.08	10.3	577		
Q	—	—	442		
24.4 B.H.P.	1.20	4.8	456		
(Hydrogen)	1.61	6.7	463		
	2.17	9.4	460		

It was found necessary to make the trials with hydrogen of shorter duration than those with coal gas, and the results in regard to exhaust heat-loss were found to exhibit some inconsistency, probably owing to there having been insufficient time for temperatures to become steady. The results, though not tabulated, show that the effects of hydrogen on the exhaust heat-losses are very similar to those of coal gas.

It will be seen that, in all cases, the heat-losses to exhaust become greater as the amount of gas is increased. The rate of increase is independent of the load on the engine, and becomes less as the amount of gas admitted is increased.

As the ratio coal-gas/air by volume is increased, the percentage heat-loss to exhaust at first increases, reaches a maximum, and thereafter diminishes, the position of the point of maximum with reference to the gas/air ratio varying according to the load.

If the percentage losses to exhaust are considered on the basis of the ratio coal-gas/fuel oil by weight, it is found, on plotting the values, that the percentage loss increases at a rate which is independent of the load on the engine and which depends solely on the ratio gas/fuel oil by weight. At all loads the point of maximum percentage loss to the exhaust appears to occur when the ratio coal-gas/fuel oil by weight is in the neighbourhood of 130 per cent.

(*d*) *Combustion and Expansion.*—In each trial two diagrams were taken with the Hopkinson optical indicator, the phase of the diagrams being adjusted to be 90 degrees in advance of the engine crank. The diagrams were afterwards magnified to 2½ times their original size by means of a Zeiss Epidiascope, and the curves were traced on to paper. Each diagram as taken with the indicator represents some five or six complete cycles. Typical diagrams obtained are shown in Fig. 7.

In examining the diagrams with a view to determining the differences produced by the admission of gas, the chief features to which attention was directed were :—

(1) The compression curve *a* to *b*.
(2) The point *b*, at which the pressure rises sharply.
(3) The slope of the curve *b* to *c*, as indicative of the rapidity of the pressure-rise.
(4) The maximum pressure.
(5) The expansion curve *c* to *d*.

These features are dealt with below in the order given.

(1) *Compression Curves.*—The suction temperature, at the different loads considered, has been calculated from the observed weight of air consumed and the measured exhaust temperature. Using these figures in conjunction with the indicated pressure at the "point of rapid pressure-rise"—*i.e.*, at the end of compression—the temperature corresponding to this point has been obtained. Table IV. shows the suction temperature, together with the pressure and temperature at the "point of rapid pressure-rise" for the three different loads considered, under normal conditions, with no gas.

TABLE IV.

Series.	B.H.P.	Suction temperature °F.	At point of rapid pressure-rise. Pressure lbs. per sq. in. (abs.).	Temperature °F.
G, L	53·7	213	305	1031
H, R	39·5	198	305	1017
J, Q	24·5	189	305	987

In view of the high temperatures and pressures during the compression stroke, it seemed possible that some degree of slow combustion might occur during this stroke.

If this were so it would be expected that the compression curves on the diagrams with gas would rise above the corresponding curves taken with no gas, since the contraction in volume caused by the combustion of hydrogen is not sufficient to mask the rise in pressure due to the heat evolved.

Taking Trial No. Q3, in which the consumption of hydrogen was 5.182 cu. ft. per min. (at 760 mm. and 15°C.), as an example, Table V. has been prepared to show the effects on the compression-pressure of the pre-burning of various amounts of the hydrogen admitted, it being assumed that 25 per cent. of the heat evolved by the pre-combustion is lost to the cylinder walls.

TABLE V.

Proportion of the H_2 admitted which is burnt during compression. per cent.	Calculated Compression-pressure. lbs. per sq. in. (abs.).
50	355
25	330
10	316
5	311
0	306

It thus appears that any appreciable degree of pre-combustion would produce a noticeable variation in the compression curves. Examination of the indicator cards, however, shows that there is no such deviation of the compression curves due to the use of either hydrogen or coal gas, and it thus appears that there can be very little, if any, combustion occurring during the compression stroke.

In this connection the adiabatic-compression experiments by Professor H. B. Dixon, F.R.S., already mentioned, are again referred to as showing that very little combustion is to be expected during the compression stroke as indicated above. In the case quoted, a mixture of five per cent. by volume of hydrogen in air, tested at a compression-ratio of 12.25 : 1, showed no explosion, the degree of slow combination occurring during the time occupied by one stroke of the oil engine under discussion being negligible.

(2) *The Point of Rapid Pressure-Rise.*—This point is taken to indicate the actual start of combustion proper. It was found that at any particular load, as the amount of gas admitted was increased, the "point of rapid pressure-rise" occurred proportionately later in the stroke. Since, however, as more gas is admitted the supply of oil is correspondingly reduced, it appeared that the position of this point might be governed, not by the amount of gas admitted, but by the quantity of oil injected, although, as previously mentioned, the quantity of fuel injected has no effect on the timing of the opening of the fuel valve.

The diagrams obtained with the Hopkinson indicator during the series of trials with no gas were therefore examined, the results being shown in Fig. 5.

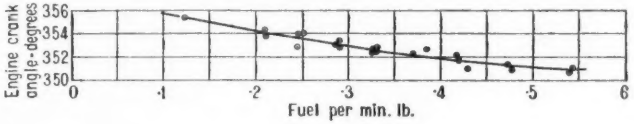


FIG. 5.

Point of rapid pressure-rise. (No gas.)

It will be seen that, as the amount of the fuel injection is increased, the "point of rapid pressure-rise" occurs earlier in the stroke. Thus with a fuel consumption of 0.5 lb. of oil per minute, the point occurs at a crank angle of 351 degrees, while if the oil supply per minute is reduced to 0.1 lb., the point occurs some five degrees later in the stroke.

In Fig. 6 is shown the position of the "point of rapid pressure-rise" at the different loads examined, according to the amount of gas admitted. It will

be seen, as already mentioned, that the point occurs later in the stroke as more gas is admitted. It appears, however, that this difference is due entirely to the reduced injection of oil accompanying the increased admission of gas. For example, consider the curve for series H in Fig. 6. With no gas admitted, the oil consumption was 0.3316 lb. per minute, and the rapid pressure-rise occurs at

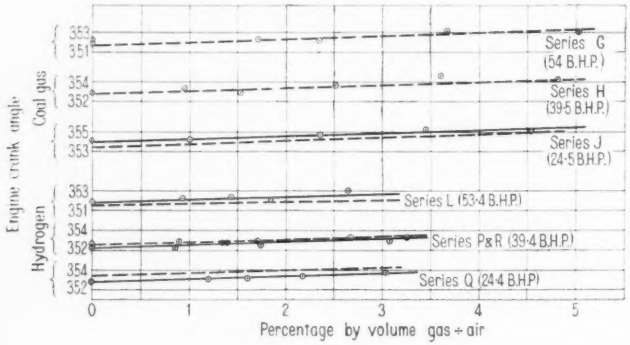


FIG. 6.

Point of rapid pressure-rise.

352.75 degrees crank angle. With 2.52 per cent. gas/air ratio the position of the point was at 353.60 degrees, while the oil consumption was 0.2532 lb. per minute. But from Fig. 5 the position of the "point of rapid pressure-rise" corresponding to 0.2532 lb. of oil per minute and no gas is 353.4 degrees. Similarly, with 4.82 per cent. gas/air ratio, the rapid pressure-rise occurs at 354.2 degrees, and the oil consumption is 0.1932 lb. per minute, but with no gas and a consumption of 0.1932 lb. per minute the position of the "point of rapid pressure-rise" is 354.2 degrees.

In this way the curves in Fig. 6, showing the variation in the position of the "point of rapid pressure-rise" with the amount of gas admitted, can be corrected for the effect of the reduced oil injection. The dotted lines in Fig. 6 show this correction, and it will be seen that there is, in general, no difference in the slope of the full lines and the corresponding dotted lines.

Thus it is evident that the gas itself produces no effect on the point in the stroke at which combustion commences, and it appears that it is the oil fuel which controls this point.

(3) *Rate of Pressure-Rise during Combustion.*—Examination of the indicator diagrams taken with and without gas, shows that there is no definite variation in the slope of the curve immediately after the point at which the rapid pressure-rise commences. The curves on the indicator cards for this part of the stroke are, however, rendered unreliable owing to vibrations, as will be seen in Fig. 7. Moreover, the slope of the portion of the curve referred to above would appear to be governed more by the period of vibration of the indicator piston, etc., than by the rapidity of combustion of the working fluid. Thus the effect of the admission of gas on the rate of pressure-rise immediately after the initiation of combustion cannot be obtained directly from the indicator curves for this part of the stroke.

Since, however, the admission of gas has the effect of reducing the maximum pressure, without reducing the time in which this pressure is attained, it seems permissible to infer that the pressure-rise is slower when gas is being admitted, and hence that the effect of the admission of gas is to lower the rate of combus-

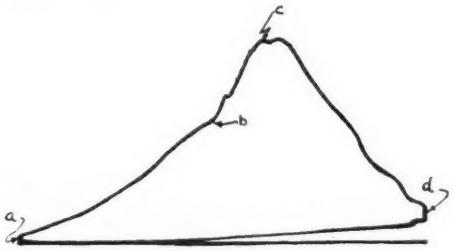
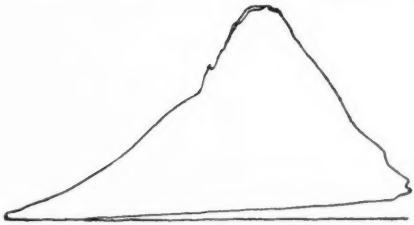
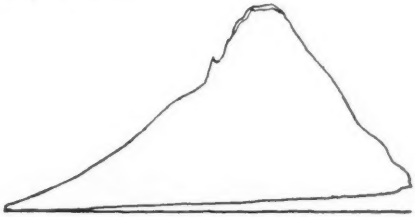


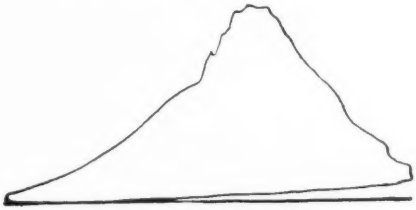
FIG. 7.
Typical 90-degree card.



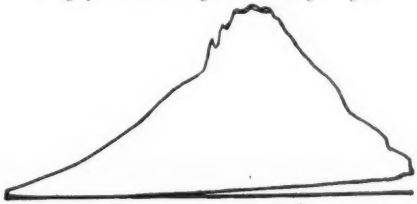
L. 1. 53·4 *B.H.P. No gas.*



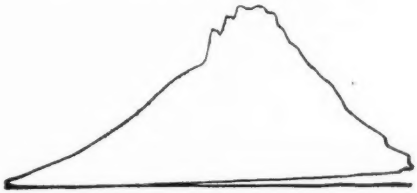
L. 5. 53·4 *B.H.P.*
2·65 *per cent. by Vol. Hydrogen.*



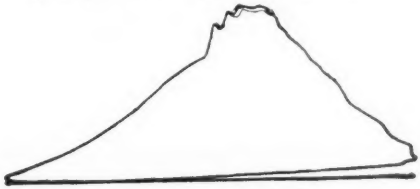
R. 1. 39·4 *B.H.P. No gas.*



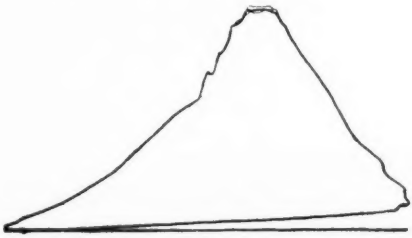
R. 3. 39·4 *B.H.P.*
3·08 *per cent. by Vol. Hydrogen.*



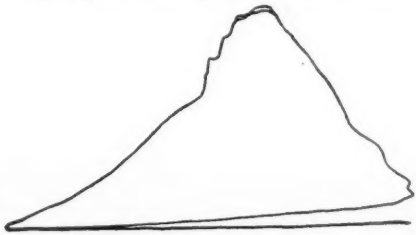
Q. 1. 24·4 *B.H.P. No gas.*



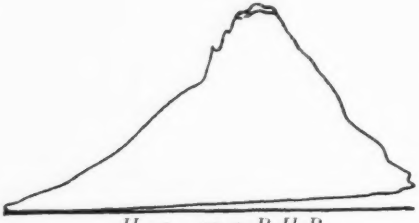
Q. 3. 24·4 *B.H.P.*
3·04 *per cent. by Vol. Hydrogen.*



G. 1. 54 *B.H.P. No gas.*

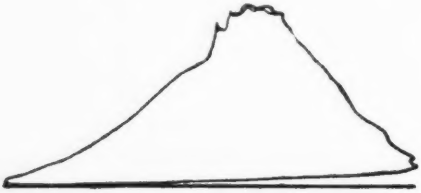


G. 3. 54 *B.H.P.*
5·03 *per cent. by Vol. Coal gas.*

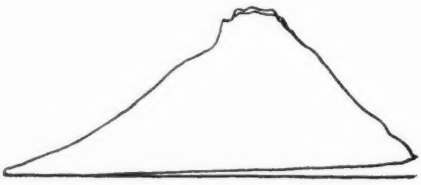


H. 2. 39.5 B.H.P.
0.95 per cent. by Vol. Coal gas.

H. 6. 39.5 B.H.P.
4.82 per cent. by Vol. Coal gas.



J. 1. 24.5 B.H.P. No gas.



J. 5. 24.5 B.H.P.
4.53 per cent. by Vol. Coal gas.

tion. If this were so, it would be expected that, after a point, the effect of the gas in delaying combustion would become less as more gas is admitted, and that finally, when a concentration was reached which would ignite spontaneously at the compression temperature and pressure of the engine, the delaying effect on combustion would disappear entirely.

This affords a possible explanation for the shape of the curves of thermal efficiency with the use of hydrogen (Fig. 2), where it will be seen that the reduction in efficiency appears to approach a minimum value as the amount of hydrogen admitted is increased. It would also be expected that this minimum value would occur earlier with hydrogen than with coal gas.

(4) *Maximum Pressure.*—Admission of either coal gas or hydrogen causes a reduction in the indicated maximum pressure, as shown in Table VI., the decrease in pressure being directly proportional to the percentage by volume of gas admitted.

In the case of hydrogen the rate of decrease in maximum pressure with increase in the ratio gas/air by volume is the same for all loads. Thus each increase of 1 per cent. in the ratio gas/air by volume causes the maximum pressure to be reduced by 4.3 lb. per sq. in.

With coal gas the rate of decrease in maximum pressure with the admission of gas appears to be more rapid at the lighter loads. Thus at the highest load dealt with (54 b.h.p.), each 1 per cent. increase in the ratio gas/air by volume causes the maximum pressure to be reduced by 4 lb. per sq. in. At 39.5 b.h.p. and 24.5 b.h.p. the corresponding reductions in pressure are 8.8 and 8.0 lb. per sq. in. respectively.

Whilst it is somewhat difficult to compare the points in the stroke at which maximum pressure occurs under different conditions, owing to the flattening out of the diagrams at this point due to combustion at constant pressure, there does not appear to be any appreciable variation due to the use of gas.

As the reduction in maximum pressure produced by the admission of a given volume of coal gas is in general greater than that produced by an equivalent volume of hydrogen, it appears that, volume for volume, coal gas has a greater effect than hydrogen in slowing up the rate of combustion.

TABLE VI.

Coal Gas.				Hydrogen.			
Series.	Gas/Air Ratio per-centage by volume.	Maximum pressure lbs. per sq. in. (abs.).	Decrease in maxi-mum pressure as a percentage of normal.	Series.	Gas/Air Ratio per-centage by volume.	Maximum pressure lbs. per sq. in. (abs.).	Decrease in maxi-mum pressure as a percentage of normal.
G & F	0	520	—	L.	0	520	—
	1.71	515	1.0		0.93	518	0.4
54	2.34	507	2.4	(53.4	1.43	511	1.7
B.H.P.	3.67	500	3.9	B.H.P.)	1.84	506	2.7
	5.03	498	4.2		2.65	503	3.3
H	0	488	—	R	0	491	—
	0.95	484	0.8		0.90	481	2.0
39.5	1.53	477	2.3	(39.4	1.38	487	0.8
B.H.P.	2.52	493	5.1	B.H.P.)	1.75	483	1.6
	3.00	451	7.6		2.08	481	2.0
	4.82	447	8.4		3.08	477	2.9
J	0	435	—	Q	0	446	—
	1.00	424	2.5		1.20	441	1.1
24.6	2.36	415	4.6	(24.4	1.61	429	3.8
B.H.P.	3.45	417	4.1	B.H.P.)	2.17	433	2.9
	4.53	400	8.1		3.04	431	3.4

(5) *Expansion Curves.*—Since at any given load, as more gas is admitted, the maximum pressure is reduced whilst the brake horse-power and the mean effective pressure of the engine remain constant, the fall in pressure during expansion must be at a slower rate.

Examination of the indicator diagrams shows that this is the case, and it is thus evident that the admission of gas causes more heat to be evolved during expansion, giving rise to the reduced thermal efficiency and greater heat-loss to exhaust observed during the trials under review.

6 *Conclusions*

(1) *General.*—The results of the trials under review show that small quantities of hydrogen or coal gas can be employed as an auxiliary fuel in a solid-injection oil engine. When gas is being admitted the engine appears to run more sweetly than when the same power is being developed with oil alone. No ill effects are produced by the use of gas beyond a slight reduction in the thermal efficiency and a slightly hotter exhaust.

(2) *Thermal Efficiency.*—With an amount of hydrogen equal to 3 per cent. by volume of the air supply to the engine, the reduction in brake thermal efficiency at the highest load dealt with (53.4 b.h.p.) is 5.3 per cent. of the normal efficiency, whilst the corresponding reduction at the lightest load (24.4 b.h.p.) is 10.9 per cent. of the normal efficiency appropriate to this load.

There are indications that as the amount of hydrogen admitted is increased, the thermal efficiency approaches a minimum value, after which it is suggested that the efficiency would again rise as the proportion of hydrogen to air became such as to ignite spontaneously at the compression temperature and pressure.

In the case of coal gas, over the range tested, the thermal efficiency falls in direct proportion to the percentage by volume of coal gas admitted, the fall being

greater at light loads. Thus for each 1 per cent. increase in the ratio coal gas/air by volume the fall in efficiency at the highest load (54 b.h.p.) is 0.52 per cent. of the normal efficiency, whilst at the lightest load dealt with (24.5 b.h.p.) the fall in efficiency is 4.0 per cent. of the corresponding normal efficiency.

(3) *Heat-Loss to Exhaust.*—The admission of small quantities of either coal gas or hydrogen gives rise to a slight increase in the amount of heat rejected to exhaust, accompanied by a corresponding increase in the temperature of the exhaust gases. The rate of increase of exhaust gas temperature with increase in the amount of gas admitted is approximately the same at all loads, and is unaffected whether coal gas or hydrogen is in use. Thus each 1 per cent. increase in the ratio by volume of gas/air causes a rise of approximately 10 degrees F. in the temperature of the exhaust gas.

(4) *Combustion and Expansion.*—It appears that the admission of such small quantities of hydrogen or coal gas as were employed in the present investigation leads to a slowing down of the rate of combustion accompanied by a reduced maximum pressure. With amounts of hydrogen up to 3 per cent. and coal gas up to 5 per cent. by volume of the air consumption of the engine, there is no noticeable pre-burning during the compression stroke, and the point in the stroke at which combustion starts is controlled by the oil fuel injection. The rapidity of the pressure-rise following the initiation of combustion appears, however, to be reduced by the admission of gas, coal gas producing a greater effect in this direction, volume for volume, than hydrogen. There are also indications that, as the proportion of hydrogen to air is increased beyond a certain point, the slowing-down effect on combustion ceases.

Over the range covered by the present experiments, it appears that the rate of decrease in maximum pressure with increase in the amount of hydrogen admitted is the same for all loads, and that each 1 per cent. increase in the ratio hydrogen/air by volume causes the maximum pressure to be reduced by 4.3 lb. per sq. in.

In the case of coal gas the rate of decrease in maximum pressure appears to be greater at reduced loads. At the highest load dealt with (54 b.h.p.) each increase of 1 per cent. in the gas/air ratio causes a reduction of 4 lb. per sq. in. in the maximum pressure, whilst at 24.5 b.h.p. the corresponding reduction is 8 lb. per sq. in.

Reduced Intake-Air Pressure

7 *Summary*

(*a*) *Introductory.*—The object of the experiments was to determine the effects produced on the performance of the engine by throttling the air intake, with a view to predicting the performance of the engine under altitude conditions.

(*b*) *Range of Investigation.*—Four series of trials were run, each at a different load, namely, 24.1, 38.7, 53.2 and 68.1 b.h.p., the speed being constant. At each load trials were run with varying degrees of throttling of the air intake, the degree of throttling being measured by the pressure at the end of the suction stroke as found from the light spring diagrams.

The range of suction pressures investigated included down to approximately 2 lb. per sq. in. below normal for the highest load (68.1 b.h.p.), and down to approximately 6 lb. per sq. in. below normal for the lightest load (24.1 b.h.p.).

(*c*) *Conclusions.*—When running at constant speed and developing a constant brake horse-power, a reduction of suction pressure appears to lengthen the time interval between injection of the fuel and the start of combustion. The rate of pressure-rise after combustion has started appears to be unaltered by a reduction of suction pressure, whilst at any given load the magnitude of this pressure-rise remains approximately the same at all suction pressures. The maximum pressure

is decreased as the suction pressure is reduced, whilst more heat is evolved by combustion during expansion. The temperature of the exhaust gases is increased, as also are the heat losses to the jackets. These effects become more pronounced as the load on the engine is increased.

In consequence of the above effects, the brake thermal efficiency is decreased by a reduction of suction pressure, whilst the fuel consumption is increased, these effects becoming relatively greater with increase in the load on the engine. Thus at 68.1 b.h.p. a reduction of 2 lb. per sq. in. in the suction pressure results in the brake thermal efficiency being reduced by some 17 per cent. of the efficiency under normal conditions, whilst at 24.1 b.h.p. the corresponding reduction in efficiency is 4.4 per cent. of the normal value appropriate to this load.

(*d*) *Application to Altitude Conditions.*—Subject to certain corrections, a reduction in suction pressure by throttling the air intake causes the same effects on the engine as are produced by altitude conditions. A Table is given in the Appendix whereby the results of the throttling trials may be applied to altitude conditions.

In general, the brake thermal efficiency falls as the altitude is increased, the rate of fall being greater at high than at low loads. At light and moderate loads the first few thousand feet above ground level cause but a slight change in the brake thermal efficiency, but as soon as the air/fuel ratio is reduced to a value of approximately 30, the fall in efficiency with further increase of altitude is very much more rapid.

8 *Introductory*

The object of the experiments dealt with in this section was to ascertain the effects on the performance of a solid-injection oil engine produced by throttling the air intake. It was further intended to apply the results so obtained in an endeavour to forecast the performance of such an engine under altitude conditions.

The expression "Intake-Air Pressure" or "Suction Pressure" is taken to denote the pressure existing in the cylinder at the end of the suction stroke, as found from the ordinate on the light-spring indicator card obtained by producing the compression curve backwards as shown in Fig. 12 (*b*).

Actually, at the end of the suction stroke, the pressure in the cylinder is given by the barometric pressure less the scale value of the ordinate "hg." The inlet valve is, however, still open, and air may enter the cylinder. If now the compression curve is produced backwards to the point "d," the ordinate "hd" is a measure of the pressure which would have produced the same effects in the engine had the inlet valve closed precisely at top dead-centre.

Two complete series of trials were run with varying suction pressures. In the first series an ordinary steam engine type indicator was used both for the light-spring and for the 90-degree advanced indicator diagrams. Later, when an optical indicator was available, it was decided to check the previous trials, and it soon became evident that, although other measurements agreed well, the suction pressure at the same throttle setting varied according to whether it was measured by the optical or by the ordinary indicator. The difference was small at small degrees of throttling, but became serious when the suction pressure was much reduced, and was apparently attributable to the friction of the pencil of the ordinary indicator altering the shape of the compression curve on the light-spring diagram, and thereby indicating a lower suction pressure than that which actually existed.

Since the whole series of experiments depended on the accuracy of the light-spring indicator diagrams, it was decided to repeat all the trials, using the optical indicator. This was accordingly done, and the results of this second series of trials are given below.

9 *Apparatus*

(*a*) *Engine.*—The engine used during the investigation was that employed during the experiments with hydrogen described above. The valve timing and equipment of the engine remained unaltered, though prior to the trials described below the engine was dismantled, the valves ground in and three new piston rings fitted.

(*b*) *Fuel.*—The fuel used was the same as that described in the previous portion of the paper.

(*c*) *General.*—The arrangement of the jackets and the exhaust calorimeter were as previously described.

During the first set of trials in which the ordinary type of indicator was used, one sample of exhaust gas was collected slowly during each trial, and at least two analyses were made of each sample, using a Bone and Wheeler gas analysis apparatus. During the second set of trials, now under review, no gas samples were collected.

In the air intake pipe, at a point between the engine and the air box, was fitted a barrel-type throttle valve provided with a pointer and scale. By manipulating this valve any desired degree of throttling could be obtained.

10 *Range of Investigation*

Four series of trials were carried out at different loads with constant speed. The trials in each particular series were run at constant speed, constant power, and varying degrees of throttling of the air intake.

The four series of trials are to be distinguished by the brake horse-power developed. The characteristic value of the brake horse-power and the minimum intake air pressure dealt with for each series are shown in Table VII.

TABLE VII.

Series.	Mean B.H.P.	Mean speed (R.P.M.).	Minimum intake air pressure lb. per sq. in. (abs.).	Mean B.M.E.P. (lb. per sq. in.).
A	24.1	213.6	7.91	25.3
B	38.7	212.9	8.90	40.7
C	53.2	211.9	11.15	56.2
D	68.1	210.8	12.27	72.3

11 *Experimental Results*

(1) *General.*—It was found that whilst at light loads the engine would run with the air intake considerably throttled, at heavy loads only a slight degree of throttling was permissible. Under heavy loads any large degree of throttling necessitated so large an increase of fuel that the governor soon came to the overload position, when the supply of fuel was automatically cut off. At the more reduced suction pressures, and particularly at heavy loads, the exhaust gas presented a cloudy and dirty appearance, and it seems probable that under these conditions a portion of the oil may dribble down the comparatively cool cylinder walls and be evacuated unburnt in the exhaust.

(2) *Brake Thermal Efficiency.*—The effects on the brake thermal efficiency of a reduction in suction pressure are shown in Fig. 8 and in Table VIII.

It is seen that as the suction pressure is reduced the brake thermal efficiency falls, the rate of fall being greater with heavier loads. It appears that at light and moderate loads the decrease in efficiency with reduction of suction pressure is at first slight, but becomes very much more rapid after a certain point is reached, this point occurring earlier as the load on the engine is increased. It appears that at all loads the increased rate of fall in efficiency occurs when the air/fuel ratio (by weight) is reduced to a value of approximately 30.

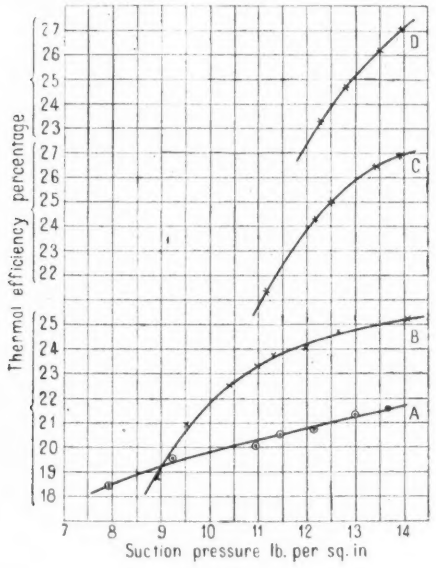


FIG. 8.

Brake thermal efficiency.

A. 24.1 B.H.P. C. 53.2 B.H.P.
B. 38.7 B.H.P. D. 68.1 B.H.P.

TABLE VIII.

Series.	Suction pressure lb. per sq. in.	Brake Thermal Efficiency (Higher Cal.) Value.	Pounds fuel per B.H.P. per hour.	Air/Fuel Ratio by weight.	Percentage volumetric efficiency.
	13.65	21.6	0.576	58.3	81.3
A	12.98	21.3	0.584	52.8	74.2
	12.14	20.7	0.601	45.4	66.1
24.1	11.42	20.5	0.607	42.0	61.6
B.H.P.	10.92	20.0	0.623	37.1	55.9
	9.23	19.5	0.638	29.5	46.1
	7.91	18.5	0.674	23.4	39.2
	14.05	25.2	0.494	41.9	81.1
	12.62	24.7	0.500	37.5	73.5
B	11.97	24.0	0.519	32.3	65.8
	11.30	23.8	0.524	29.6	61.2
38.7	10.96	23.3	0.535	26.8	56.6
B.H.P.	10.40	22.5	0.554	23.5	51.3
	9.51	20.9	0.596	20.1	47.2
	8.90	18.8	0.663	15.9	41.6
C	13.91	26.9	0.464	31.7	80.5
	13.41	26.4	0.473	28.4	73.9
53.2	12.51	25.0	0.499	24.3	67.0
B.H.P.	12.17	24.3	0.513	21.7	61.6
	11.15	21.4	0.583	16.6	53.7
D	13.96	27.0	0.461	24.5	78.9
	13.49	26.2	0.476	22.8	76.1
68.1	12.78	24.7	0.505	19.7	70.0
B.H.P.	12.27	23.3	0.535	17.1	74.8

With the fuel employed the theoretical air/fuel ratio for complete combustion is 14.4.

(3) *Fuel Consumption.*—As the suction pressure is reduced, the speed and brake horse-power remaining constant, the fuel consumption per brake horse-power increases, the rate of increase with reduction of suction pressure becoming greater as the load on the engine is increased. At all loads the rate of increase in fuel consumption with reduction of suction pressure becomes considerably greater after the air/fuel ratio has been reduced to approximately 30.

There is some evidence, particularly at the lower suction pressures and with heavy loads, that some of the fuel injected into the cylinder passes out without being burnt, although analysis of the exhaust gases showed that in general no carbon monoxide or unburnt hydrocarbons were present, even at the most reduced suction pressures.

The effect of reduction of suction pressure on the fuel consumption is shown in Fig. 9 and Table VIII., whilst Table IX. has been prepared from the observations recorded in Table VIII. to show more clearly the changes in thermal efficiency and in fuel consumption.

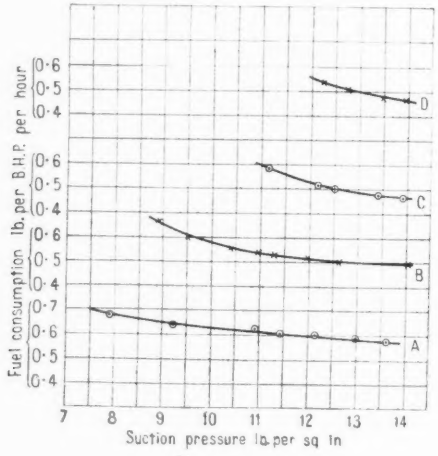


FIG. 9.

Fuel consumption, lb. per B.H.P. per hour.

A. 24.1 B.H.P. C. 53.2 B.H.P.
B. 38.7 B.H.P. D. 68.1 B.H.P.

(4) *Heat Losses to Jackets.*—The arrangement of the jackets was such that the same cooling water passed in turn through the cylinder barrel jacket and the breech jacket, whilst the water temperature was measured at entry to, and exit from, both jackets. During the trials under review the amount of this cooling water was not measured, though the temperatures mentioned above were noted. Thus although the actual heat losses to the two jackets were not measured, the relative magnitude of these losses was obtained.

It will be noted that the jacket losses include the amounts of heat given up by the gases during the exhaust stroke and conducted from the exhaust port, etc., which quantities should in reality be credited to exhaust.

The effects of a reduction in suction pressure on the relative heat losses to the cylinder barrel and breech and to the exhaust are shown in Table X.

It will be seen that, out of the total of the heat lost to the cylinder barrel and breech, the proportion lost to the barrel decreases in direct proportion to the reduction of suction pressure, the rate of decrease being somewhat greater at heavy than at light loads. The proportion lost to the breech shows a corresponding increase as the suction pressure is reduced, the rate of increase becoming greater with increase in the load on the engine.

TABLE IX.

Reduction in suction pressure below normal (taken as 14lb. per sq. in.).	Decrease in Brake Thermal Efficiency as a percentage of efficiency at 14lb. per sq. in.			
	A. 24.1 B.H.P.	B. 38.7 B.H.P.	C. 53.2 B.H.P.	D. 68.1 B.H.P.
1 lb. per sq. in. ...	2.3	1.6	3.9	7.2
2 ,, ,, ...	4.4	3.8	11.4	17.3
3 ,, ,, ...	6.5	7.3	22.6	—
4 ,, ,, ...	8.8	13.5	—	—
5 ,, ,, ...	11.3	23.6	—	—
6 ,, ,, ...	14.6	—	—	—

Reduction in suction pressure below normal (taken as 14lb. per sq. in.).	Increase in fuel consumption per B.H.P. per hour as a percentage of consumption at 14lb. per sq. in.			
	A.	B.	C.	D.
1 lb. per sq. in. ...	.7	1.2	4.7	7.2
2 ,, ,, ...	1.7	4.1	13.2	20.7
3 ,, ,, ...	4.1	8.2	29.4	—
4 ,, ,, ...	6.5	18.0	—	—
5 ,, ,, ...	10.3	32.7	—	—
6 ,, ,, ...	15.4	—	—	—

(5) *Heat Loss to Exhaust.*—It will be seen from Table X. that the gross amount of heat lost to the exhaust increases in direct proportion to the reduction of suction pressure, the rate of increase becoming greater as the load on the engine is increased. The heat lost to the exhaust, when expressed as a percentage of the heat supplied in fuel, at first increases slightly with reduction of suction pressure, but at all loads a point is soon reached when further reduction of suction pressure causes the percentage loss to exhaust to decrease, the rate of decrease becoming greater as the suction pressure is further reduced.

It will be noticed that the observed values of the heat losses to exhaust do not show great consistency. As the suction pressure was reduced the exhaust temperature increased, as did the temperature of the unlagged exhaust calorimeter. There is no doubt that an increasing amount of heat was lost to the air by " radiation " as the suction pressure was reduced. The heat value of any fuel passing out unburnt in the exhaust has also been neglected, which quantity should in reality be credited to exhaust.

(6) *Exhaust Gas Composition and Temperature.*—During the trials under review no exhaust gas analyses were made. As has already been mentioned, however, exhaust gas analyses were carried out during a previous series of similar trials. The results of these analyses showed that no carbon monoxide or unburnt hydrocarbons are contained in the exhaust gases even at the most reduced suction pressures, though it is thought probable that when the suction pressure is greatly reduced, and particularly at heavy loads, some fuel may pass out unburnt in the exhaust.

The temperature of the exhaust gas was measured by means of a mercury thermometer inserted in a pocket in the exhaust pipe at a point close up to the exhaust port.

The results are shown in Table XI., and it will be seen that at all loads the exhaust gas temperature increases with reduction of suction pressure. At all

TABLE X.

Series.	Suction pressure lb. per sq. in.	Distribution of heat-loss to jackets. Percentage to barrel.	Percentage to breech.	Heat-loss to exhaust. B.Th.Us. per min.	Percentage of heat value in fuel.
	13.65	48.1	51.9	1,700	36.3
A	12.98	47.6	52.4	1,796	37.4
	12.14	46.9	53.1	1,818	36.7
24.1	11.42	45.9	54.1	1,709	34.3
B.H.P.	10.92	45.4	54.6	1,702	33.3
	9.23	43.5	56.5	1,558	29.7
	7.91	43.6	56.4	1,668	30.2
	14.05	45.6	54.4	2,093	32.0
B	12.62	44.9	55.1	2,154	32.5
	11.97	44.0	56.0	2,297	33.4
38.7	11.30	43.5	56.5	2,201	31.7
B.H.P.	10.96	42.9	57.1	2,336	33.0
	10.40	38.6	61.4	2,230	30.8
	9.51	40.4	59.6	2,377	30.2
	13.91	41.7	58.3	2,978	35.3
C	13.41	40.6	59.4	3,183	37.1
	12.51	39.3	60.7	3,278	36.5
53.2	12.17	37.3	62.7	3,345	35.9
B.H.P.	11.15	37.3	62.7	3,320	31.5
D	13.96	37.6	62.4	3,569	33.4
	13.49	35.7	64.3	3,713	33.7
68.1	12.78	34.0	66.0	3,885	33.2
B.H.P.	12.27	33.5	66.5	4,176	33.6

TABLE XI.

Series.	Suction pressure, lb. per sq. in.	Exhaust temperature, °F.
	13.65	430
	12.98	458
A	12.14	503
	11.42	521
24.1 B.H.P.	10.92	552
	9.23	631
	7.91	707
	14.05	539
	12.62	561
B	11.97	635
	11.30	672
38.7 B.H.P.	10.96	704
	10.40	757
	9.51	835
	8.90	922
	13.91	673
C	13.41	721
	12.51	796
53.2 B.H.P.	12.17	852
	11.15	961
D	13.96	805
	13.49	847
68.1 B.H.P.	12.78	927
	12.27	1001

loads the rate of increase becomes greater as the suction pressure is reduced, and, at the same suction pressure, the rate is greater with heavier loads.

(8) *Compression Pressure and Maximum Pressure.*—During each trial two 90-degree advanced indicator cards were taken with the optical indicator in addition to the light-spring cards, typical diagrams being shown in Fig. 10.

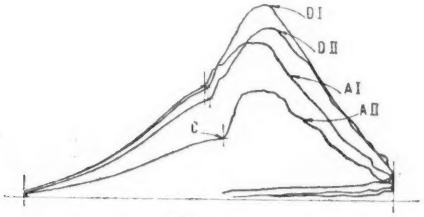


FIG. 10.

Typical 90-degree cards.

Series A. 24.1 B.H.P.

I. 13.65 lb. per sq. in. suction pressure.
II. 7.91 ,, ,, ,,

Series D. 68.1 B.H.P.

I. 13.96 lb. per sq. in. suction pressure.
II. 12.27 ,, ,, ,,

In Table XII. is shown the effect of a reduction of suction pressure on the indicated maximum and compression pressures. The "Compression Pressures" shown in Table XII. refer to the pressure at the point C on the typical diagrams given in Fig. 10. This point is taken to mark the start of combustion proper, and will be referred to as the "point of rapid pressure-rise."

It will be seen from Table XII. that the compression pressure decreases in direct proportion to the reduction of suction pressure, the rate of decrease being the same for all loads. Thus for each reduction of 1 lb. per square inch in suction pressure the compression pressure is reduced by 26 lb. per square inch irrespective of load.

At all loads a reduction of suction pressure causes a corresponding decrease in the indicated maximum pressure, the rate of fall of maximum pressure being constant for any one load, but increasing as the load on the engine is increased.

(9) *"Point of Rapid Pressure-Rise."*—With reduction of suction pressure the "point of rapid pressure-rise" is found to occur later in the stroke, as will be seen from Fig. 11 and Table XIII. The effect in this direction of a given reduction in suction pressure becomes progressively greater as the load on the engine is increased.

Observations with the "spark indicator" showed that the time of lifting of the sprayer needle valve is uninfluenced by the amount of the fuel injection. During the trials under review the mean value of the crank angle at injection was 348.8 degrees.

Under normal conditions the position of the "point of rapid pressure-rise" is influenced by the amount of fuel injected per stroke, the pressure-rise occurring earlier as the quantity of oil per injection is increased. This effect is discussed above in connection with the use of hydrogen, where a curve (Fig. 5) is given showing the variation in the position of the "point of rapid pressure-rise" according to the magnitude of the fuel injection under normal conditions.

It thus appears that the variations in the position of the " point of rapid pressure-rise," as shown in Fig. 11, include some effect due to the amount of fuel injection, since as the suction pressure is reduced, under constant load, the fuel injection is augmented. This effect is shown by the dotted lines in Fig. 11, the points in which were obtained by taking the observed fuel consumption for each trial and ascertaining what would be the position of the " point of rapid pressure-rise " appropriate to it under normal conditions of suction pressure, the values being taken from the curve referred to above.

TABLE XII.

Series.	Suction pressure, lb. per sq. in.	Indicated compression-pressure lb. per sq. in. (gauge).	Indicated maximum pressure, lb. per sq. in. (gauge).	Decrease in maximum pressure for each 1lb. per sq. in. reduction in suction pressure, lb. per sq. in.
	13.65	299	432	
A	12.98	272	405	
	12.14	251	376	
24.1	11.42	231	365	24.7
B.H.P.	10.92	215	341	
	9.23	176	301	
	7.91	154	287	
	14.05	296	474	
B	12.62	273	442	
	11.97	247	423	
38.7	11.30	236	398	28.6
B.H.P.	10.96	224	390	
	10.40	200	368	
	9.51	188	358	
	8.90	167	335	
C	13.91	295	501	
	13.41	279	480	
53.2	12.51	255	455	39.0
B.H.P.	12.17	236	431	
	11.15	214	395	
D	13.96	302	550	
	13.49	296	525	
68.1	12.78	277	488	49.0
B.H.P.	12.27	264	475	

It will be seen that the effect of reduced suction pressure is slightly greater than is indicated by the observed variations in the position of the " point of rapid pressure-rise," and that the true effect is given by the difference in the slope of the full and the dotted lines in Fig. 11. The position of the " point of rapid pressure-rise " according to suction pressure, corrected for the effects of the variation in fuel consumption, is given in Table XIII.

(10) *Combustion and Expansion.*—Examination of optical indicator diagrams taken at the same load with different suction pressures shows that the rate of pressure-rise following the start of combustion is not altered by changes of suction pressure, the slope of the curve between the " point of rapid pressure-rise " and maximum pressure being the same at all suction pressures.

At any particular load the magnitude of the pressure-rise following combustion remains almost unaltered by changes of suction pressure.

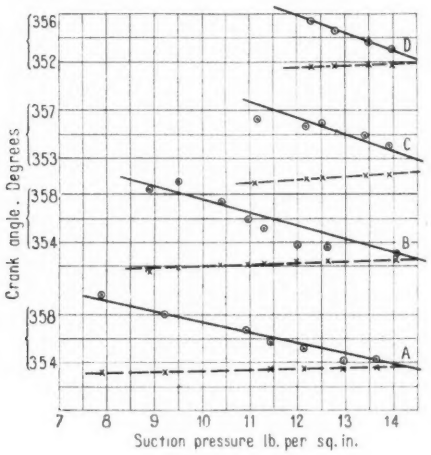


FIG. 11.

Point of rapid pressure-rise.

A. 24.1 B.H.P. C. 53.2 B.H.P.
B. 38.7 B.H.P. D. 68.1 B.H.P.

TABLE XIII.

Series.	Suction pressure, lb. per sq. in.	Crank angle at point of rapid pressure-rise.	Corrected amount by which "Point of rapid pressure-rise" is retarded by each 1lb. per sq. in. decrease in suction pressure.
	13.65	354.5	
	12.98	354.2	
A	12.14	355.2	
	11.42	355.7	0.9 degrees.
24.1 B.H.P.	10.92	356.8	
	9.23	358.0	
	7.91	359.6	
	14.05	353.1	
	12.62	353.6	
B	11.97	353.8	
	11.30	355.2	1.1 degrees.
38.7 B.H.P.	10.96	355.9	
	10.40	357.4	
	9.51	359.1	
	8.90	358.4	
	13.91	354.1	
C	13.41	354.9	
	12.51	355.9	1.4 degrees.
53.2 B.H.P.	12.17	355.7	
	11.15	356.3	
D	13.96	353.1	
	13.49	353.6	1.5 degrees.
68.1 B.H.P.	12.78	354.6	
	12.27	355.4	

Since, as the suction pressure is reduced at any given load, the mean effective pressure remains practically unchanged whilst the maximum pressure is diminished, it is to be expected that the fall of pressure during expansion must be at a slower rate as the suction pressure is lowered. Examination of the expansion curves shows that this is the case.

XII.—*Conclusions.*

(1) *Brake Thermal Efficiency.*—When running at constant load and with constant speed, the brake thermal efficiency of the engine falls as the suction pressure is reduced, the rate of fall being at first comparatively slow. As the suction pressure is reduced a point is reached after which a further reduction in suction pressure leads to a much more rapid fall in efficiency, this point occurring earlier as the load on the engine is increased.

It appears that when the air/fuel ratio by weight is reduced, either by throttling the air-intake or by increasing the load, to a value in the neighbourhood of 30, the rate of fall of brake thermal efficiency with reduction of suction pressure becomes more rapid. It appears, moreover, that the rate of fall in efficiency, both before and after this value is reached, is approximately independent of the load on the engine.

At the highest load considered (68.1 b.h.p.) a reduction of 2 lbs. per sq. in. in the suction pressure results in the brake thermal efficiency being reduced by some 17 per cent. of the thermal efficiency under normal conditions. At the lightest load (24.1 b.h.p.) the corresponding reduction in efficiency is 4.4 per cent. of the normal thermal efficiency appropriate to this load.

(2) *Fuel Consumption.*—At all loads the fuel consumption per brake horsepower increases as the suction pressure is diminished. With air/fuel ratios above approximately 30, the rate of increase in fuel consumption with reduction of suction pressure is slow, but this rate shows considerable increase if the air/fuel ratio is reduced below 30. Thus, when delivering 68.1 b.h.p. a reduction of 2 lbs. per sq. in. in suction pressure causes the fuel consumption per brake horsepower per hour to increase by 20.7 per cent. of that under normal conditions. At the lightest load dealt with (24.1 b.h.p.) the corresponding increase would be 1.7 per cent. of the normal consumption at this load.

(3) *Heat-Losses to Jackets and Exhaust.*—Of the total of the heat lost to the cylinder barrel and breech, the proportion lost to the barrel decreases in direct proportion to the reduction in suction pressure, the rate of decrease being somewhat greater at heavy than at light loads. The proportion lost to the breech shows a corresponding increase as the suction pressure is reduced.

The amount of heat lost to the exhaust increases in direct proportion to the reduction of suction pressure, the rate of increase being greater at heavy than at light loads.

Expressed as a percentage of the heat supplied in the fuel, the heat-loss to exhaust at first increases slightly with reduction of suction pressure, but at all loads a point is soon reached after which a further reduction of suction pressure causes the percentage loss to exhaust to decrease.

(4) *Exhaust Gas Composition and Temperature.*—No carbon-monoxide or unburnt hydrocarbons appear to be formed under the conditions covered. When the suction pressure is greatly reduced, and especially at heavy loads, the exhaust gases become cloudy and dirty, and it appears that some of the fuel injected is evacuated unburnt in the exhaust.

The temperature of the exhaust gas increases with reduction of suction pressure, the rate of increase being greater at heavy loads. Thus a reduction of 2 lbs. per sq. in. in suction pressure causes a rise of 255°F. in the exhaust temperature at 68.1 b.h.p. At 24.1 b.h.p. the corresponding increase in temperature is in the neighbourhood of 70°F.

(5) *Combustion and Expansion.*—As the suction pressure is reduced, there is a longer delay between injection and the point in the stroke at which occurs the rapid rise in pressure denoting the start of combustion. For the same reduction in suction pressure this effect is greater at heavy than at light loads. Thus at 68.1 b.h.p. the amount by which the "point of rapid pressure-rise" is retarded for each 1 lb. per sq. in. decrease in suction pressure is 1.5 degrees crank angle, whilst at 24.1 b.h.p. the amount would be 0.9 degrees.

The rate of pressure-rise after combustion has started appears to be unaltered by a reduction of suction pressure, whilst at any given load the magnitude of this pressure-rise remains approximately the same at all suction pressures.

The indicated maximum pressure is reduced in proportion to the reduction of suction pressure, the rate of decrease, whilst constant for any one load, becoming greater as the load on the engine is increased.

The fall of pressure during expansion takes place at a slower rate as the suction pressure is reduced, and it appears that the amount of heat evolved by combustion during the expansion stroke is increased by a reduction in suction pressure.

In conclusion, the author wishes to acknowledge his indebtedness to the very valuable help and advice of Professor A. H. Gibson, at whose suggestion the experiments were commenced.

APPENDIX

Application of the Data Obtained to Altitude Conditions

(1) *General.*—Under altitude conditions not only is the pressure at the end of the suction stroke reduced, but the back-pressure on the exhaust stroke is also lowered, whilst the fall in air temperature at altitude must also be considered.

The various factors governing the relation between the effects of throttling and of altitude will therefore be considered under three separate headings:—

(*a*) Weight of charge drawn into the cylinder per stroke.
(*b*) Back-pressure.
(*c*) Suction temperature and other effects.

In Table XIV. are shown the variations in air pressure, temperature and density with height. The figures are taken from a paper by Dr. E. G. Ritchie* and represent the mean conditions for the South of England:—

TABLE XIV.

Altitude in feet.	0	5,000	10,000	15,000	20,000
Pressure (lb. per sq. in.) ...	14.65	12.35	10.15	8.25	6.7
Temperature °F.	52	39	24	5	−15
Density (lb. per cu. ft.) ...	0.0785	0.0676	0.0570	0.0486	0.0415

(2) *Effect of Altitude on Weight of Air entering the Cylinder.*—The air consumption of the engine was measured by means of the air box during the throttling trials, and using these observations in conjunction with the readings of the barometer and the air temperature, the volumetric efficiency of the engine was obtained. The results are shown in Table VIII.

Curves were then prepared for each series showing volumetric efficiency plotted against suction pressure. It was found that, except at greatly reduced suction pressures, one curve sufficed to represent series A and series B, whilst a second curve would represent series C and series D.

* See AERONAUTICAL JOURNAL, August, 1921.

The value of the volumetric efficiency at different suction pressures was then used as a basis for calculating the altitude corresponding to each suction pressure. The method is best explained by considering an example :—

Assuming 14 lbs. per sq. in. to be the normal suction pressure at ground level, the normal volumetric efficiency at ground level for series A (24.1 b.h.p.) is 85.0 per cent. from Table VIII., thus the engine draws in 85.0 lbs. of air in a certain number of strokes. At ground level 85 lbs. of air occupy 1082.8 cu. ft. If the suction pressure is reduced to 13 lbs. per sq. in., the engine takes only 74.5 lbs. of air in the same number of strokes. Hence, if the 1082.8 cu. ft. air weigh only 74.5 lbs., the air density is 0.0688 lb. per cu. ft. This density corresponds, from Table XIV., to an altitude of 4,340ft. Thus from the point of view of the weight of air inspired per stroke, an altitude of 4,340ft. will produce the same results (at 24.1 b.h.p.) as occur when the air-intake is throttled at ground level so as to give a suction pressure of 13 lbs. per sq. in., and it appears that this method of comparison affords an approximate means by which the throttling trials may be applied to a consideration of the effect of altitude.

Table XV. shows the above method applied to the results of the throttling trials, whilst in Table XVI. the same information is shown in a more convenient form.

TABLE XV.

	"Suction Pressure" in Throttling Trials. lb. per sq. in.						
	14	13	12	11	10	9	8
Series A 24.1 B.H.P. Volumetric Efficiency ...	85	74.5	64.8	56.9	50.5	44.9	39.5
Corresponding Density, lb. per cu. ft.	0.07850	0.06881	0.05986	0.05255	0.04664	0.04148	0.03648
Corresponding altitude, ft. ...	0	4340	8600	12,510	16,280	20,000	24,000
Barometric pressure at altitude	14.65	12.68	10.75	9.18	7.82	6.70	5.65
Air temperature at altitude, °F.	52	41	28	15	0	−15	−33
Series B 38.7 B.H.P. Volumetric Efficiency ...	85	74.5	64.8	56	48.8	42.1	—
Corresponding Density, lb. per cu. ft.	0.07850	0.06881	0.05986	0.05172	0.04507	0.03889	
Corresponding Altitude, ft....	0	4340	8600	13,020	17,350	22,020	
Barometric Pressure at Altitude	14.65	12.68	10.75	8.08	7.48	6.14	
Air Temperature at Altitude, °F.	52	41	28	13	−4	−24	
Series C 53.2 B.H.P. and Series D 58.1 B.H.P. Volumetric Efficiency ...	81.5	70.6	61.2	52.7	—	—	—
Corresponding Density, lb. per cu. ft.	0.0785	0.0680	0.0590	0.0508			
Corresponding Altitude, ft....	0	4750	9020	13,540			
Barometric Pressure at Altitude	14.65	12.50	10.59	8.78			
Air Temperature at Altitude, °F.	52	40	27	11			

(3) *Exhaust Back-Pressure.*—If it be assumed, for the moment, that for the same reduced suction pressure the expansion and compression curves remain the same whether the low pressure at the end of suction be produced by throttling or by altitude, then the light-spring card obtained at high altitude would be as shown by the full lines in Fig. 12 (*c*).

Fig. 12 (*a*) shows a typical light-spring card obtained with the air intake considerably throttled. The diagram (*b*) illustrates the normal light-spring card at the same load, the final suction pressure being below atmospheric by an amount given by the ordinate *hd*.

In Fig. 12 (*c*) the diagrams (*a*) and (*b*) have been placed together so that the points *b* and *d* coincide. The heavy lines then show the suction card which

would be obtained at the altitude necessary to give a final suction pressure equal to that corresponding to the diagram (*a*).

TABLE XVI.

Altitude, feet.	"Suction Pressure" in Throttling Trials. lb. per sq. in. A 24.1 B.H.P.	B 38.7 B.H.P.	C 53.2 B.H.P.	D 68.1 B.H.P.
0	14	14	14	14
2,000	13.56	13.56	13.60	13.60
4,000	13.10	13.10	13.17	13.17
6,000	12.62	12.63	12.71	12.71
8,000	12.14	12.14	12.25	12.25
10,000	11.64	11.67	11.80	11.80
12,000	11.12	11.22	11.35	
14,000	10.60	10.78	10.90	
16,000	10.06	10.34		
18,000	9.52			
20,000	9.00			
22,000	8.45			
24,000	8.00			

Thus, assuming the expansion and compression curves to remain unaltered, it appears that the amount of work represented by the difference between the areas *afg* and *akmg* in Fig. 12 (*c*) should be credited to the engine when the reduced suction pressure is produced by altitude as opposed to throttling.

It also appears that the area included between the exhaust and atmospheric lines will be nearly the same whether the reduced pressure is produced by throttling or by altitude conditions, in which case the amount of indicated work gained is given by the difference between the areas *efg* and *hkmg* in Fig. 12 (*c*), the latter area being that at normal suction pressure at the load considered.

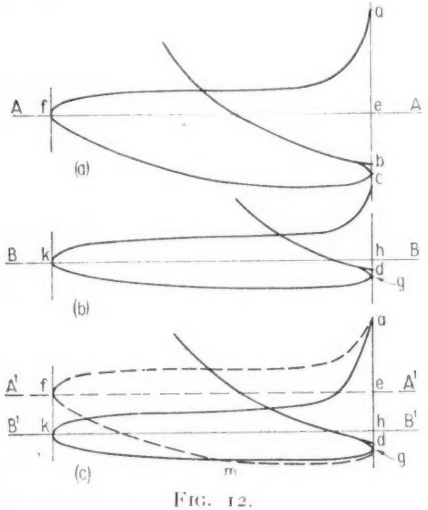


FIG. 12.

Light-spring card.

In Table XVII. are shown the extra amounts of work to be credited to the engine when applying the scale of altitude given in Table XVI. to the previous results of the throttling trials. The amount of work in each case is that appro-

priate to the actual suction pressure which would obtain in the cylinder at the altitude considered, it being assumed that the normal suction pressure at ground level is 14 lbs. per sq. in., and that under altitude conditions the suction pressure is always 0.65 lb. per sq. in. below barometric pressure.

TABLE XVII.

Altitude, feet.	Additional Brake Horse-Power due to diminished Back-Pressure			
	A 24.1 B.H.P.	B 38.7 B.H.P.	C 53.2 B.H.P.	D 68.1 C.H.P.
0	0.00	0.00	0.00	0.00
2,000	0.47	0.54	0.58	0.60
4,000	0.91	1.04	1.13	1.16
6,000	1.28	1.45	1.61	1.64
8,000	1.61	1.82	2.06	2.06
10,000	1.93	2.14	2.43	2.45
12,000	2.14	2.42	2.73	
14,000	2.36	2.69	3.03	
16,000	2.52	2.84		
18,000	2.67	3.01		
20,000	2.79	3.17		
22,000	2.91	3.27		
24,000	3.01			

It should be mentioned that in calculating the additional amounts of work done due to diminished back-pressure, the values of the mechanical efficiency assumed for the four series A, B, C, D are 67, 76, 82 and 85 per cent. respectively.

(4) *Suction Temperature and other Factors.*—At the altitude shown in Table XVI. as corresponding to any particular suction pressure, the same weight of air enters the cylinder per stroke, but at a lower temperature. The pressure is also reduced. There will also be a less weight of residual gas in the clearance volume at the commencement of suction, whilst the temperature and pressure of this gas will be lower. The effect of the reduced temperature of the residual gas may be neglected since, neglecting the difference in specific heats, any increase in volume of the air drawn in due to contact with the residual gas is nullified by the corresponding contraction of the residual gases. Again, at the start of the suction stroke the relative pressures of the residual gas and the entering air are the same under altitude conditions as they are under the corresponding conditions in the throttling trials. If, moreover, the jacket water temperature is unchanged, it seems improbable that the slight difference in absolute temperature and pressure at the end of suction in the two cases will have any material effects, and it thus appears that the process of combustion and expansion will remain substantially unaltered.

Hence the altitude scale given in Table XVI. may be applied without further correction to the results of the throttling trials in the case of the following factors:—

Compression and maximum pressures.
Combustion and expansion.
Composition of exhaust gas.

(5) *Heat Losses.*—Since at the altitude conditions corresponding to any given suction pressure in the throttling trials (Table XVI.) the conditions during compression, combustion and expansion are unchanged, the heat losses during these portions of the cycle will be unaltered. At release a larger amount of gas will be evacuated immediately, whilst the weight, temperature and pressure of the gas remaining in the cylinder during the exhaust stroke will be reduced. Thus the heat losses to the walls and breech during the exhaust stroke will be diminished, whilst those to the exhaust will be correspondingly augmented.

As, however, only a comparatively small proportion of the losses to the cylinder walls and breech occurs during the exhaust stroke, it appears that an approximate idea of the heat losses occurring under altitude conditions may be obtained by applying the scale of altitude suction pressure given in Table XVI. directly and without correction to the results of the throttling trials.

(6) *Thermal Efficiency and Fuel Consumption.*—From the preceding arguments it appears that, when applying the altitude suction pressure scale given in Table XVI. in an examination of the effects of altitude conditions on the thermal efficiency and fuel consumption of the engine, the only correction necessary is that due to the effects of back pressure.

Table XVIII. embodies this correction and shows the effect of altitude on the thermal efficiency and fuel consumption.

TABLE XVIII.

	Brake Thermal Efficiency per cent.				Lb. of Fuel per Brake Horse-Power per hour.			
	A 24.1 B.H.P.	B 38.7 B.H.P.	C 53.2 B.H.P.	D 68.1 B.H.P.	A 24.1 B.H.P.	B 38.7 B.H.P.	C 53.2 B.H.P.	D 68.1 B.H.P
0	21.7	25.2	26.9	27.1	0.574	0.494	0.463	0.460
2,000	21.9	25.3	26.9	26.6	0.569	0.492	0.463	0.469
4,000	22.0	25.5	26.7	26.0	0.564	0.489	0.467	0.479
6,000	22.2	25.5	26.2	25.1	0.562	0.488	0.476	0.497
8,000	22.2	25.4	25.4	23.9	0.561	0.489	0.492	0.521
10,000	22.2	25.3	24.4	22.0	0.560	0.492	0.511	0.554
12,000	22.2	25.1	23.1		0.562	0.497	0.539	
14,000	22.1	24.7	21.6		0.565	0.505	0.577	
16,000	21.9	24.1			0.569	0.518		
18,000	21.7	23.2			0.574	0.537		
20,000	21.5	22.2			0.580	0.562		
22,000	21.2	20.8			0.588	0.599		
24,000	20.8				0.598			

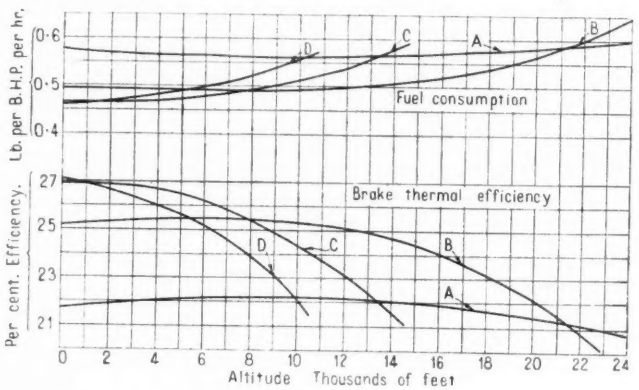


FIG. 13.

Performance at altitude.

A. 24.1 B.H.P. C. 53.2 B.H.P.
B. 38.7 B.H.P. D. 68.1 B.H.P.

It will be seen from Table XVIII. and Fig. 13 that, in general, the brake thermal efficiency falls as the altitude is increased, the rate of fall becoming greater as the load on the engine is increased. Whilst, in general, the first

few thousand feet above ground level cause but a relatively slight fall in efficiency, a point is reached, depending on the load, at which the efficiency commences to fall rapidly with further increase in altitude. The altitude at which this point occurs is higher at low loads than at high ones, and corresponds to a value of the air/fuel ratio in the neighbourhood of 30.

It is further noticeable that at light loads the brake thermal efficiency at first shows a tendency to rise slightly as the altitude is increased above ground level. This appears to be due to the fact that under these conditions the air/fuel ratio is not greatly altered, whilst the pumping losses are materially reduced.

Discussion

The Chairman: I think you will all agree that the author has acquitted himself nobly in giving such an excellent summary of this long paper in half an hour. This subject at the present time is very interesting to us because we hope that before the end of next year both the Government airship, being built at Cardington, and the Airship Guarantee Co.s airship, being built at Howden, will be launched. Therefore, the question of the utilisation of hydrogen is a matter of extreme importance to those who are interested in airships. I think I am right in saying that Commander Cave-Browne-Cave, who during the war was in charge of the technical side of the Royal Naval Airship Station at Kingsnorth, assisted by Major Abell—who is present this evening—was the first to carry out actual experiments with the use of hydrogen with airship engines. I will therefore call on Wing Commander Cave-Browne-Cave to open the discussion. As you know, it is the custom for these meetings to be opened alternately by members of the Institution of Automobile Engineers and the Royal Aeronautical Society and this time it falls to the lot of the Royal Aeronautical Society. I therefore call on Wing Commander Cave-Browne-Cave.

Wing Commander Cave-Browne-Cave: First of all, I want to thank the author for his paper. Many people would have despaired of being able to use a single cylinder engine running at 200 r.p.m. to determine facts of interest in connection with the use of hydrogen in airship engines or of compression ignition engines at altitude, but let me assure the author that his work and his suggestions communicated in this paper are of great interest.

Perhaps I might enlarge a little on what the Chairman has said on the value of burning hydrogen in an airship engine. As the oil fuel of an airship is consumed, and her weight thereby decreased, she will tend to rise. It is, of course, possible to keep her at the desired level by steering downwards, but that makes a totally unnecessary demand on the engine power and is inefficient. In any case, at the end of the flight it is necessary to restore the ship to static equilibrium in order that she can be landed safely. Therefore it is necessary to discharge a certain amount of the buoyant hydrogen to compensate for the fuel consumed. The quantity is a certain definite amount and is referred to as the aerostatic equivalent of the fuel burned. If that hydrogen can be burned in the engine instead of being discharged, a considerable amount of power can be derived from it and the necessary oil fuel thereby reduced. R.101 would require 25 tons of fuel for the Egypt flight. If she can burn the hydrogen, which must otherwise be wasted, the oil fuel load can be reduced to a little over 20 tons and therefore nearly five tons extra paying load can be carried. As the mail rate, even by steamship to Egypt, is over one shilling per pound an extra five tons of paying load is worth having.

The other respect in which the burning of hydrogen may be important is that it may improve the actual functioning of the engine itself. It was hoped

that the introduction of hydrogen would speed up the burning so that the combustion of the oil would be instantaneous as the oil was introduced into the cylinder. One of the greatest difficulties in the process of burning oil in a high speed compression ignition cylinder is in controlling the delay in burning. If it were only possible to eliminate this delay so that each particle of oil as it entered the cylinder was instantaneously burned, the rate of pressure rise could be definitely controlled by regulating the speed of admission. That is purely a mechanical problem. It was hoped that the admission of hydrogen with the air into the cylinder would cause the combustion to be more instantaneous and therefore give a means of more absolute control over the rate of pressure rise. The author's experiments, however, indicate that the effect of introducing hydrogen is to slow down the rate of combustion. Some work, which I hope will be described later in the discussion, has been done by Ricardo and leads to an opposite conclusion. It is therefore necessary to examine exactly the respects in which the author's engine differs from a typical airship engine and I hope that to these may be added the figures for the engine which Mr. Ricardo used for his tests. The speed of the typical airship engine is about 1,000 r.p.m., whereas the speed of the author's engine was 210 r.p.m. The b.m.e.p. of the airship engine is about 100 lbs./in., whilst in the case of the author's it was 56. An important difference lies in the excess air coefficient, which for an airship engine is about 30 per cent.. but in the author's engine was 100 per cent. The ratio of hydrogen to oil by weight, based on the aerostatic equivalent, is 8.25 per cent. and in the author's tests it was 14 per cent., so that he is using a greater proportion of hydrogen to oil. It may be convenient, however, to concentrate all the hydrogen to be used in a few of the engines and in these the ratio may be increased to 16 per cent. or 24 per cent. The high excess air ratio is unfortunate because the ratio of hydrogen to air in the author's work is 3 per cent. as compared with the more usual airship figure of 6 per cent. at full power and 4 per cent. at half power. I think Mr. Ricardo's engine was very fairly closely similar to the airship engine.

Let me summarise the differences between the results which the author has obtained and those which Mr. Ricardo obtained, because I suggest this is the essential point on which the discussion should hinge. The author says that by the introduction of hydrogen the burning is slowed, the maximum pressure is reduced and the temperature of the exhaust gases is raised. Ricardo showed that the rate of burning was faster and that the maximum pressure was higher and that, in fact, the amount of hydrogen which it was possible for him to burn was limited by the bumpiness of the running of the engine. The author also says that the thermal efficiency of the engine fell off slightly as hydrogen was added, but Ricardo found no difference. The author's evidence rests largely on the diagrams. I am not sufficiently expert in engine indicators to say what amount of weight should be given to the evidence of these diagrams taken with the optical indicator. The thermal efficiency and the exhaust temperature are perhaps stronger evidence in support of the facts which he deduces.

Can we arrive at a physical explanation of what happens? Perhaps when hydrogen is present the oil takes considerably longer to find the oxygen with which it is to burn. Presumably the hydrogen, having a greater affinity for oxygen than has the carbon, will first seize the oxygen it requires. The particles of oil are then surrounded by the air much diluted with steam and nitrogen. It is interesting, however, that if the same power is developed from a mixture of oil and hydrogen as from oil alone, the hydrogen will take up the oxygen it requires and will still leave a slightly higher proportion of air available for the remaining oil. Now Ricardo worked with a comparatively small excess air coefficient whilst the author worked with a big one. Therefore one would have expected that the effect of the dilution with hydrogen would have been more pronounced in Ricardo's case than in the author's.

I should be very interested to know why the author did not use more hydrogen. There was no indication, so far as I can see, that any dangerous point was reached and the conclusions would, I think, have been far more definite if the proportion of hydrogen used could have been increased right up to some definite limit which prevented more being used. In the case of Ricardo's work, that was reached at the excessive bumpiness of the engine.

The second part of the paper deals with the behaviour of a compression engine at altitude. That is very interesting. I am not quite sure that I follow entirely the method by which the author relates the results obtained from the engine sucking from a reduced pressure with those that would be obtained at altitude. I think the main difference is that he has made no correction for the temperature of the air, which at considerable altitudes is very cold. The result of reducing the suction pressure is, I imagine, exactly what would have been anticipated, viz., that the burning would be slower, the efficiency lower and the exhaust temperature higher. One interesting point in the author's results is that the unburned fuel coming out of the exhaust was largely in the form of carbon. We have also recently been carrying out some experiments by taking a compression ignition engine up to equivalent altitude and we found the same thing. That is interesting because it may indicate exactly what happens during combustion in the cylinder. If the particle of oil is cracked into carbon and combustible gases, and the combustion is incomplete, you will have an unburned particle of carbon sent out. If, on the other hand, the particle of oil remains as oil and burns at its surface, you will have a fine oil rain sent out. So far as we have been able to observe, you only get particles of dry carbon and I think the author's results confirm that, but I should be very interested if he or anybody else can add any information as to the nature of the dirt in the exhaust.

I do not in the least anticipate that the author is short of any further work to do on his engine, but it would be very interesting if he could extend his tests to show what is the effect of pre-heating the air before it goes into the compression ignition cylinder, and I suggest pre-heating progressively up to 200°C. so as to get a well defined effect. It may tend to speed up combustion; if so, it would be very valuable.

The CHAIRMAN: I need hardly remind you that Wing Commander Cave-Browne-Cave is intimately associated with the Government airship at Cardington. In fact, it is largely due to his enthusiasm, which has never been damped on the many occasions when airships have been scrapped or threatened with extinction. He has kept them alive and he has earned our gratitude for this work. I will now ask Mr. Chorlton, of Messrs. Beardmore, who has devoted much of his time during the past few years to the development of engines for airships, to speak.

Mr. A. E. L. CHORLTON: I should first like to add my congratulations to those of the foregoing speaker to the author for his interesting paper. There are so many points of inquiry in it that it is not possible to go into them all. Commander Cave-Browne-Cave has already dealt with some of them and so I will mention one or two others.

In the early stages of the proposition for the construction of airships, the engines were considered at a meeting in which Mr. Ricardo and I were concerned. I then held the opinion that we could burn hydrogen at the same time as the heavy fuel in the engine cylinders, and so my first satisfaction on hearing the paper is to learn that this can be done.

There are in the paper points that I am not quite so clear about, but what I say must not be taken as criticisms but inquiries, because I fully understand that in making tests, as these have been made, upon an engine of this character, one is bound to maintain so many of the factors constant to get comparisons

that a lot may be missed, and it is in this respect that the author rather fails to come up to what practical people, who have to make the actual engines and get them to work, had hoped for. The author does not, it would appear, emphasise the air content as much as he might have done, considering its importance.

The internal combustion engine depends upon the air that gets into the cylinder. This is really the first consideration, and as an engine to work in the air must of course have the maximum amount present, one expects it to be stressed. From this point of view, the first thing that strikes me is, "Why is his engine working at comparatively low mean pressures?" Commander Cave-Browne-Cave has already referred to this. He marked on the board 100 lbs. and 56 lbs. minimum. Crossley's, the makers of the engine, have built this class of engine for some years, but some time before that I was concerned in engines built by Ruston's, of Lincoln, and they would not work an engine at a mean pressure of 56 lbs. if they expected to make any profit on sales. Therefore, one wonders why they are working under low pressure conditions—what is the reason? We must conclude that if the air content is there, there must be some other reason. The volumetric efficiency does not seem bad; can we conclude that the spraying itself is inefficient, that the atomiser is not acting properly? Can we say that the oil was burnt as it ought to have been? Further, was the hydrogen burnt as it ought to have been (considered separately)? I hope the author will correct me if I am wrong, but can you burn hydrogen without proper carburation or mixing?

What the paper seems to convey is, that the fuel is not burnt efficiently, whether it be hydrogen or oil. How did the author assure himself that he was getting the right mixture, so to speak, in both cases? Commander Cave-Browne-Cave has made some remarks as to the comparison between an engine burning paraffin and hydrogen and the heavy oil combination referred to in the paper. He believed Mr. Ricardo used paraffin and, of course, it was vaporised before it was drawn into the cylinder.

Commander CAVE-BROWNE-CAVE: I was referring to Ricardo's experiments with heavy oil.

Mr. CHORLTON: I am afraid I have not those figures. If we deal with the point as regards increased rate of combustion, we have got to suppose that as nearly as possible a perfect mixture has been obtained and also to be sure that the necessary turbulence and rate of combustion is present. There is no indication in the paper, however, that this consideration has been safeguarded, but from what I know of Mr. Ricardo, I am perfectly certain that he would have got all these things in proper shape before he went any farther with the experiments. If you are going to work on a progressively attenuating mixture, as the author did, either you must deal with turbulence or advance your point of ignition in order to combat the weakening of it. Such variations he may tell us would not give a parallel series of results; quite true, but he might tell us after he had made this test how he had been able to effect any improvement. Every test in the paper showed that by progressively diminishing the supply of ordinary fuel on the one hand and increasing the hydrogen on the other, higher exhaust temperatures were obtained. Professor David, of Leeds, has done so much in connection with delaying combustion in internal combustion engines that this would no doubt delight him. The author has got a state of delayed combustion to such an unusual extent that one did hope to hear how he proposed to overcome it.

Speaking of the use of hydrogen in an airship engine, the results of the paper are, of course, an advance, but is burning the hydrogen in the main engines the right way to do it? It may be thought to be convenient to have air,

oil and hydrogen in the same cylinder, but it is certainly difficult; is not the best way to burn the hydrogen in a separate engine?

In mentioning the low compression pressure and the low mean effective pressure, I have also noted the low maximum pressure. If you are going to obtain high economies, you must work with higher maximum pressures. At present I am in a minority of one in regard to this line of development, but we shall see what will take place in the next two years.

We are working on an engine, of which you may have heard, for airship purposes, and the results are very hopeful. Thermal efficiencies up to 40 per cent. having been due to rather better atomisation than was the case with the author, or what? We cannot say that our volumetric efficiency is any better than that of the author, but we get over 100 lbs. mean pressure and the compression, of course, is higher. The ratio is over 12 to 1, but that does not account for all the difference by any means. I notice the author refers to a lag between the actual injection period and the point of ignition and that this is always the same, whatever the amount of the injection, *i.e.*, the point of ignition; this is due to the use of a cam for injection as in the Crossley engine. With a weaker and weaker mixture and a lower maximum flame temperature, we can afford to advance the point of ignition.

Naturally the author has been careful to make all his tests on the same basis, but it is important that he has not given us anything to show what the differences might have been with further modifications and adjustments. It may be intriguing to know that at one time I had a very definite problem to face with a fixed point of injection, and the engine being reversible, would not allow of this point being altered. After a lot of trials, however, we found that by putting in a 30 ft. pipe we could so delay matters as to overcome the difficulty. We were able to vary the injection by the length of pipe sufficiently to suit this object and then make the engine truly reversible. In one case the author casts some reflection on exhaust analyses; I do not know whether he really means it; further, I wonder quite what he means.

Many years ago I examined a lot of exhausts and made many exhaust analyses. We used in test to right away examine the exhaust to ascertain whether there was any unburned fuel in it, but here we find that whatever the conditions of burning, there seems to be no unburned fuel in the exhaust. This is a strange thing.

I should like to finish up by saying that papers of this nature read before a combined meeting are very valuable and there ought to be more of them. I do not attend meetings very much myself because I am perhaps a bit lazy, but I think I should be willing to overcome my laziness if this sort of thing were extended. Nothing pleases me more than to have papers presented from different parts of England and Scotland, where original work of this description is done which may be useful to all of us, either in airships or in our ordinary business. If I can help in any way at all, I shall be extremely pleased to do so, and that is why I am so glad to listen to a paper like this and to congratulate the author upon it.

Mr. W. A. Tookey: The great interest of this paper to me is that the results are generally in accordance with one's expectations, although, as Mr. Chorlton has already said, the type of engine under test is really capable of higher efficiencies than those obtained by the author. An engine of 10.3 volume ratio should reach a thermal efficiency of about 43 per cent. on the i.h.p. basis (lower value), and this at 24.5 b.h.p. output would be equivalent to 25.0 brake thermal efficiency instead of 22—the highest noted in Table II.—for this load by the author. It shows beyond doubt that some tuning-up would have brought about better figures and probably, as Mr. Chorlton has also remarked, the instant of ignition consequent upon somewhat unusually late fuel injection timing was the

prime cause of the relatively low efficiencies reached during the trials. Highest efficiencies can be expected only by correlated injection timing with general cylinder temperatures according to the load, and this fact is of particular importance in aeronautical engines.

The author has followed the usual practice of presenting his results, output in b.h.p., mean pressures in b.m.e.p., gas and fuel/air ratios in percentage by volume and by weight, etc., and Commander Cave-Browne-Cave has just referred to air-fuel ratios for other engines in terms of 30 to 100 percentage excess over the theoretical quantity based on combustion formulæ. I personally find it difficult to appreciate and to compare engine performances when mixture strengths are so stated.

When comparing the b.h.p. efficiencies at the various outputs it must also be borne in mind that these are affected very materially by the mechanical and fluid resistances remaining more or less uniform at all loads; so that while the b.h.p. efficiency for tests L, R and Q in Table II. without hydrogen varied from 28.1 to 26.7 and to 22.0 (lower value), the assumption of the usual 20 lb. friction m.e.p. at all loads for engines of the type tested would infer 38.1, 39.6 and 39.3 i.h.p. efficiencies (lower value), thus putting a different complexion altogether on the results as reported and affecting the lessons to be learnt from the tables; the differences between the relative b.h.p. efficiencies being thus shown to be mainly due to mechanical and not physical causes.

To limit my remarks, I propose only to deal with two main points—(*a*) mixture strength in relation to power output, and (*b*) the throttling method of estimating at sea-level the probable performance of engines at an altitude. In regard to the first, I prefer to discard all air/fuel ratios which are applicable only to the particular type of liquid or gaseous fuel concerned and instead to compare performances and efficiencies on the fundamental units of pressure produced from heat units consumed, for upon these units h.p. outputs and efficiencies are really calculated. Having dealt with this subject in a paper read so recently as April, 1926, before the Diesel Engine Users' Association, I propose now to point out that if Pm or Pn refer to the mean effective pressure for i.h.p. or b.h.p. respectively, and if Qt refers to the number of b.th.u. contained in one cubic foot of piston displacement volume plus clearance volume, the ratio $Pm \div Qt = Tm$ or Tn (for i.h.p. or b.h.p.) is equivalent to Em or $En \times 5.4 \times (r \div \{r-1\})$.

In the engine used by Mr. Mucklow $r = 10.3$; $r \div (r-1)$ is therefore $10.3 \div 9.3 = 1.1075$. At 100 per cent. thermal efficiency Tm or $Tn = 5.4 \times 1.1075 = 5.98$; and thus for line one of L section in Table II. of the paper $Tn = 5.98 \times .281 = 1.68$ for lower calorific value; and for the Pn (brake m.e.p.) $= 56$ as line four of Table I., the number of heat units present in one cubic foot of total cylinder volume, $Qt = 56 \div 1.68 = 33.3$.

Similarly, for the first line of each series of trials with fuel oil the values of Tn and Qt are as tabulated below:—

	Pn	*Tn $En \times 5.98$	*Qt $Pn \div Tn$	*$\frac{Tm}{Pn+20}$ Qt
L from Table I. ...	56.0	1.680	33.3	2.28
R	41.2	1.595	25.8	2.37
Q	25.4	1.315	19.3	2.35
G and F	56.5	1.71	33.0	2.32
H	41.3	1.565	26.4	2.32
J	25.6	1.31	19.55	2.33

* Pn = Brake M.E.P.
En = Brake Thermal Efficiency (lower value.)
$Tn = Pn \div Qt$.
Qt = B.Th.U. p.c.ft. of total cylinder volume.

(A column for Tm has been added in order to appreciate as a "first estimation" the effect of mechanical and fluid resistances as already explained, it being assumed that these resistances are normal and amount to 20 lb. per sq. inch in round figures.)

From the last column (Tm) it will be obvious that Mr. Mucklow's trials, with fuel oil only, were satisfactorily comparable, but the results attainable with proper timing should have been equivalent to $Tm = 2.57$, with Qt values of about 20—as Q and J trials. Indeed, better results were obtained in the trials A, B, C, D (Table VI.) for normal suction pressures and the first lines of each set are retabulated as follows:—

	*Pn	Tn	Qt	Tm
A	25.2	1.375	18.4	2.46
B	40.7	1.613	25.4	2.39
C	56.2	1.71	32.8	2.32
D	72.3	1.715	42.2	2.19

* From Table V.

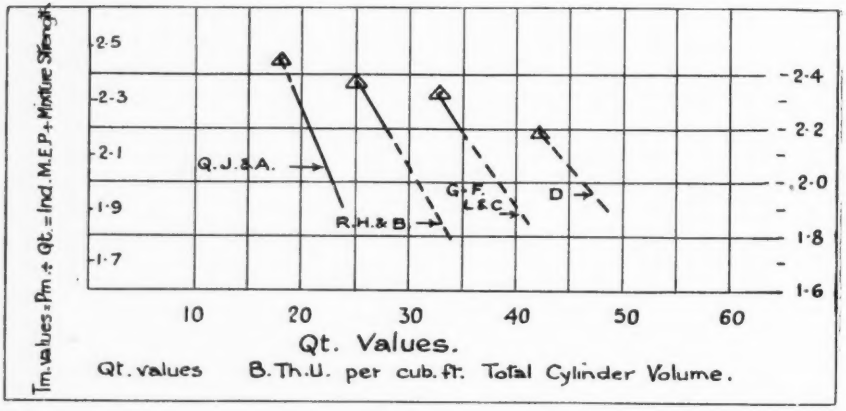


FIG. 1.

I have plotted the values of Qt and Tm in Tables II. and VI. in the Fig., and as will there be seen the performances for each of the four points of the load range follow the same curve, the only difference being that the varied suction pressures from Table VI. extend the curves as indicated by the dotted lines.

It would consequently appear that the addition of hydrogen or a mixed coal gas containing 28 per cent. of inerts produces similar effects to those of deliberately throttled charges, namely, the lowering of charge temperature and thus increasing relative density. As such effects have not been compensated for by ignition timing the thermal efficiency of the engine has suffered accordingly.

When Ricardo's test results for hydrogen only and petrol and kerosene mixtures are similarly plotted they present similar features, as will be seen from the Fig. There are many useful comparisons indicated by these curves, but it would be out of place here to deal with them at any length.

With regard to the throttling tests to approximate altitude conditions, I have found by experience that instead of throttling down as described in the paper, it is preferable to insert an additional full-way valve in an extension of the air inlet manifold and to fit a vacuum gauge between this valve and the normal inlet to the cylinder or carburettor. By running a few trials with the

additional valve fully open the reading of the gauge gives datum points for sea-level operating conditions. Subsequent "altitude" trials are made with partially closed valve so that the gauge reading then corresponds to the difference

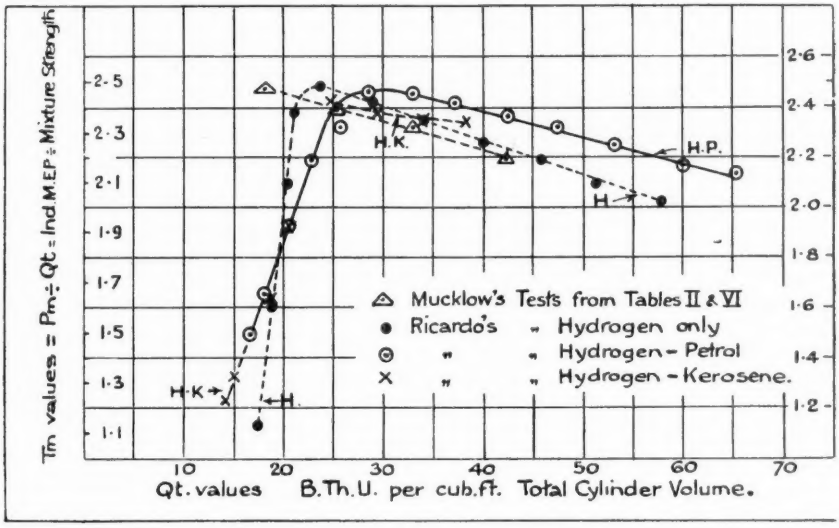


FIG. 2.

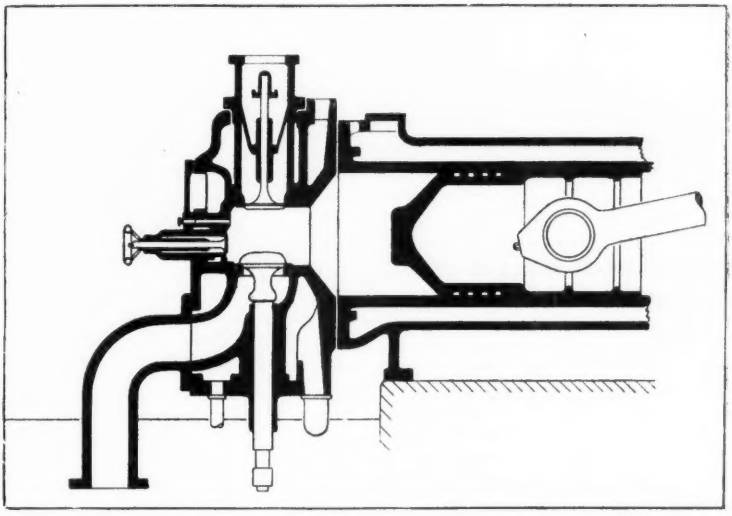


FIG. 3.

between 30 inches and the barometric pressure for any particular altitude. This method has the advantage of not interfering with the normal control settings and thus turbulence and volumetric efficiencies are unaffected except as the direct

result of the lower inlet pressures prevailing in the inlet manifold extension. I adopted this method when testing at Manchester a 300 k.w. gas-driven alternator, required to work at 15 per cent. overload under commercial guarantees at Salisbury (Southern Rhodesia), where the normal barometer is 25.3 inches. It was gratifying to find that when the set was subsequently re-tested at its destination the actual performances were in complete accord with the Manchester tests and, in fact, were slightly better, due partly, as the author has intimated, to the fact that the gases were then exhausted under the lower barometric pressure there existing as compared with sea-level conditions.

Mr. POMEROY: When I left this country eight years ago we were talking about turbulence and when I come back I find you still discussing turbulence. During the time I have been away I have had a little to do with Diesel engines and have had some experience which might throw light on the anomalies to which Mr. Chorlton has referred. This has to do with the general design of combustion chambers. I do not think there is anything in the engine design now which is more important that the combustion chamber, because such curious things can arise from microscopic alterations to its shape. During the past few years combustion chambers have been subjected to classification and degrees of merit awarded for each. Yet I know of an engine with a substantially rectangular "T" head of uniform depth which according to popular theory is as bad as can be, giving a b.m.e.p. of 113 lbs. per square inch, compression ratio 4.8 : 1. In another case the alteration of the direction of the air inlet valve elbow on a Diesel from being parallel to the crankshaft and at right angles to it made all the difference between very good running and no running at all. I have every sympathy with anybody whose experimental work depends upon the ghostly qualities of combustion chambers to say nothing of the ghostly qualities of the spraying apparatus as used on Diesel engines. With regard to the second part of the paper, I have only one remark to make. It seems to me that when we have a valve diagram such as is given in the paper, in which there is an overlap of 57 degrees between the inlet valve opening and the exhaust valve closing, it must seriously affect the accuracy of the results at closed throttle. There is a heavy suction in the inlet pipe which under conditions of valve overlap, allow a considerable quantity of exhaust gas to flow into the inlet pipe, this seriously diluting the ingoing air. This condition is particularly manifest when attempting to get good idling in automobile engines, and I think the results in this paper with regard to the ratio of air and fuel, during part throttle conditions, might be considerably affected if the valve setting was such that there was no overlapping.

Major ABELL: I was associated with the early experiments on using hydrogen as fuel at Kingsnorth, but Commander Cave has, I think, mentioned practically all the points which occur to me as far as airships are concerned, and I do not think I can amplify what he has said in any way. There is, however, one point which occurs to me regarding the burning of hydrogen in the combustion chamber. There is apparently the possibility of the formation of water in small quantities which may, to some extent, account for the retardation of the combustion of the oil in the experiments described. I remember when we started with our hydrogen experiments in an airship engine in 1917, we used to get considerable quantities of water formed which was, no doubt, due to the hydrogen combining with the oxygen in the cylinder. Of course we never attempted running at anything like full power, and, I believe, we only developed 12-15 h.p. out of an engine at that period. I should like to congratulate the author on the way he has handled what is, to my mind, a very difficult problem.

Mr. MUCKLOW, replying to the discussion, said: It is with considerable diffidence that I approach the task of replying to the remarks of the gentlemen

who have spoken to-night, since most of these gentlemen have a far wider experience of the solid-injection engine than I have.

I will endeavour to reply first to Wing Commander Cave-Browne-Cave's remarks, which were of the utmost interest, especially in view of his long and close association with the problem in hand.

In suggesting an explanation of the difference between my results and those which Mr. Ricardo obtained on a solid injection engine, I am somewhat at a disadvantage, since I have not the full particulars of the trials referred to. It seems, however, that the results of both Mr. Ricardo's trials and my own are in agreement as showing that no increase in efficiency is to be expected from the use of hydrogen, and that its use does not affect the speed of combustion to any remarkable extent.

I believe I am right in saying that the compression ratio of the engine used by Mr. Ricardo was somewhat higher than that of the Crossley, whilst the normal maximum pressures were about 800 lbs. per square inch as opposed to a figure in the neighbourhood of 500 lbs. per square inch in my experiments. These differences might well account for the increase in maximum pressure and the bumpiness experienced by Mr. Ricardo. I understand, moreover, that the increase in maximum pressure when the bumpiness occurred was only of the order of some 3 or 4 per cent. of the normal maximum pressure. In addition, the effects of any hot spot in the cylinder must not be forgotten. The Crossley engine has an essentially cool cylinder, whilst in a small high speed engine running at a high m.e.p., the conditions are favourable to the existence of hot spot. It seems likely that the existence of any hot spot in the cylinder would give rise to the bumpiness and high maximum pressures which occurred in the trials quoted.

In any case, I understand that in Mr. Ricardo's trials the increased maximum pressures did not occur till the ratio hydrogen to air by volume had been increased to a figure higher than that used in the case of my experiments. As mentioned in my paper, it seems certain that if the amount of hydrogen is increased sufficiently, a point will occur when the oil fuel will no longer control the commencement of combustion. When this point is approached, roughness of running and high maximum pressures are to be expected.

With regard to the maximum amount of hydrogen used—the question originally put to us was whether the small quantity of hydrogen representing the aerostatic equivalent of the oil fuel burnt in an airship could be used satisfactorily. Having shown that this small amount of hydrogen could be used satisfactorily with no outstanding effect on the rapidity of combustion, there did not appear to be any point in proceeding further, especially as the consequences of detonation or pre-ignition in a 14-inch cylinder might have been serious.

In his remarks on the second portion of the paper, Wing-Commander Cave-Browne-Cave mentions that no correction has been made for the reduced air temperature at altitude. It is indeed true that there is no direct correction, but the main effect of the reduced temperature—*i.e.*, its effect on the air density—is however allowed for in the method given for comparing the throttling trials with the effects of altitude.

As to the form in which any unburnt fuel is evacuated in the exhaust—the exhaust calorimeter used is such that the cooling water comes into direct contact with the exhaust gases. At reduced suction pressures a kind of dry black scum appeared on the water collected from the calorimeter, the scum consisting more of carbon than of oil.

I agree with the speaker's suggestion that the effects of preheating the air supply would afford an interesting line of investigation and shall bear the suggestion in mind.

With regard to Mr. Chorlton's remarks, I think that his first question, as to why such low m.e.p.'s and maximum pressures were used, may be due to a misunderstanding. The figure of 56lbs. per square inch which he quoted for the b.m.e.p. by no means represents full load conditions, and is of course greatly exceeded when working at higher loads. The spraying and atomising of the fuel are performed at least as efficiently in the Crossley engine as in other engines of the type.

The reason for using light loads during the trials under review was that a smaller supply of oil fuel was required, and that in consequence the ratio by weight of hydrogen to fuel oil was greater. The influence of load was provided for by running trials at several loads.

There can be little doubt that the mixing of the hydrogen with the air supply—the term carburation can surely hardly apply—was thoroughly carried out. The gas was admitted to the air intake pipe in which the air would be moving at high velocity. Further mixing would occur during passage through the inlet port and inlet valve and during the whole of the compression stroke, whilst the design of the piston and combustion chamber, as indicated by the sketch appended, is such that a high degree of turbulence is promoted towards the end of compression.

I am afraid that I do not altogether follow Mr. Chorlton's remarks when he refers to the increased exhaust temperature and the delayed combustion ensuant on the admission of hydrogen. One of the objects of the experiments was to determine whether such a delay would be produced, or whether the reverse effect would occur, as had been suggested.

I agree with Mr. Chorlton that it is highly probable that by advancing the timing of injection when using hydrogen the thermal efficiency would be raised. In addition, the performance of the engine at light loads would no doubt be improved by an earlier injection.

In regard to exhaust gas analyses, I think that there is some doubt as to whether a sample of gas collected in the usual way from the exhaust port is a true sample of the working fluid at the end of expansion. There is a possibility of dilution with air during the portion of the cycle when exhaust is not occurring, in addition to the fact that combustion may still be proceeding to some extent during the passage of the gas through the exhaust port.

Mr. Tookey's remarks are most interesting, and I am obliged to him for his most illuminating exposition of his method of comparing performances and efficiencies under different conditions.

The method employed for measuring the degree of throttling, by producing the compression curve backwards, was adopted in order to surmount any difficulty due to the overlap in the valve diagram. An indicator was indeed fitted in the intake pipe as advocated by Mr. Tookey, but it was difficult to decide whether to adopt as the basis of comparison the maximum depression recorded or the depression corresponding to the end of the suction stroke. For this reason, and since it is the effective pressure at the end of the suction stroke which is the really important factor, the method described in the paper was adopted.

Mr. Pomeroy draws attention to the large overlap between the inlet valve opening and the exhaust valve closing. This may not have such serious effects as would at first appear, since the valves open and close quite slowly.

It seems, moreover, that any harmful effects due to this overlap would be reflected in the volumetric efficiency. The measured volumetric efficiencies were, however, satisfactory, so that any effect due to the overlap can have been of but small importance.

In conclusion, I must thank those gentlemen who have taken part in the discussion for their most interesting remarks.

Commander F. L. M. Boothby, R.N.: I much regret that I am unable to be present at the reading of Mr. G. F. Mucklow's most interesting paper. His work, combined with that of Mr. Ricardo, has carried to a conclusion the experiments which the engineer officers at Pulham, Messrs. Bellamy and Binding, had in hand when the Air Ministry closed down the station. The possibilities of the use of hydrogen in airship engines, and the advantages accruing therefrom must now be clear to all who care to investigate the data made available.

I should now like to suggest to Mr. Mucklow that he should take in hand a study of the exhaust gases which are formed when running on a mixture of hydrogen with petrol, kerosene and Diesel oil respectively. We may take it that helium is never likely to be available at sufficiently low cost for commercial work, and that hydrogen will have to be used with its inherent operational advantages. When hydrogen is used there is always some danger of fire, unless oxygen can be entirely excluded from its neighbourhood. This is particularly so when valving gas into the trunks of a rigid airship where an explosive mixture may be formed, and an electric charge may travel down the column of escaping hydrogen and cause an explosion in the trunks. If these trunks were full of an inert gas before valving commenced no explosive mixture could be formed. Further, if an inert gas is placed all round the hydrogen in the gas bags the hydrogen should be quite safe from fire, as we know from experiment that every form of incendiary bullet can be fired through hydrogen so protected without evil results.

In the exhaust gases from the motors we have a sufficient supply of inert gas for our purpose except in the case where an airship is diving rapidly, which will not usually occur in commercial work. We now require apparatus to purify our exhaust gases, and remove anything that may be harmful to the fabric or structure of the airship. Speaking from my own inadequate experience in the matter, once any oil is removed there would appear to be nothing to do any harm except an excess of moisture. In dry climates it would be useful to have a slightly moist gas round the gas bags, as it would keep them in better condition, and I would like to suggest that an investigation into suitable means for removing oil or any other deleterious matter from the exhaust gases, and varying the moisture content to suit the climate flown in, is the next step in the series of useful and interesting investigations now concluded by Mr. Mucklow, and I hope he will take it in hand.

THE USE OF BAROMETRIC CHARTS IN THE NAVIGATION OF AIRSHIPS[1]

BY NORMAN L. SILVESTER, M.SC., F.R.MET.SOC.

Introduction

Experience has shown how dependent is the airship upon weather conditions —more particularly for a safe ascent and descent. The numerous experiments with windscreens, tractors, mooring posts and landing gear emphasise the difficulty of handling an airship on the ground and of manœuvring it in and out of its shed.

It is in the endeavour to minimise these risks that this study has been undertaken. In the discussion as to the most advisable course for an airship to adopt for its own safety when surprised by unfavourable weather, it should be remembered that in all the examples which follow, it is a case of "making the best of a bad job"; and that no pilot would wittingly leave his base with the knowledge of such bad weather impending except under pressure of war time necessity. It is hoped to demonstrate that in some cases it might be possible by skilful navigation, aided by the frequent communication of isobaric charts by wireless telegraphy and by accurate positions given frequently by the same means, for a pilot to keep in the air during the passage of bad weather and thus avoid the risk of wreck by attempting a premature landing.

It is assumed for the purpose of this discussion that a state of war exists between the Allies and the Central Powers and hence that no enemy airship bases are available for the emergency.

In the calculations and plotting of courses it is assumed that we are dealing with an airship capable of:—

(1) Maximum speed of 55 m.p.h.[2]
(2) Cruising speed of 40 m.p.h.
(3) Carrying 48 hours' fuel.
(4) Ascending to a maximum altitude of 20,000 feet.
(5) Being handled on the ground in safety in a wind whose mean velocity is under 20 m.p.h.

The following methods which will be examined in different cases for the extrication of the airship from an area of danger due to the high winds of an approaching disturbance, should be considered merely as tentative, not as rules for navigators such as are promulgated for the use of mariners in the case of tropical cyclones;[3] nor are they exhaustive in their scope.

A. Methods which involve the flight of the airship at a uniform level in the gradient wind, *i.e.*, the wind at about 1,500—2,000 feet above the surface.

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[1] This paper was written in 1918, whilst serving with the Naval Meteorological Service. At the time of transfer to the R.A.F. it fell into the hands of the Meteorological Office, to whom application for permission to publish was made in 1921. Permission was refused, but four years later, when the R.33 broke adrift from her mooring post, the Meteorological Office advised flying a course suggested in this paper, with which they were previously in disagreement. Permission was then given for the publication of the paper.

[2] Miles per hour.

[3] *Barometer Manual*, M.O. 61, 1916, p. 77.

I. Flying into the wind.

(*a*) To steer a direct course with the wind on the starboard bow in the hope that the wind would moderate with increase in distance from the centre of the disturbance.

(*b*) To steer a direct course with the wind on the port bow in order to reach the centre of the depression where there is a possibility of an area of calm or of light winds, and having gained the centre to move with the low centre in the hope that it will pass over a suitable mooring or housing base.

(*c*) To steer a direct course with the wind on the starboard bow in order to reach an area of light wind in the rear of the depression.

This course is applicable to the special case of a fast moving low, travelling in the normal direction from W. to E. with the airship in the S.E. or S.W. quadrants.

II. Flying with the wind.

(*a*) To steer a course with the wind on the starboard quarter with the object of regaining the starting point after circumnavigating the depression.

(*b*) To steer for the area of calm between a primary and secondary depression and upon reaching this area to maintain this relative position until a suitable base is passed over.

B. Methods involving flight at different altitudes.

I. When driven to leeward in the N.E. or N.W. quadrants of a low moving from W. to E. to climb to higher altitudes in search of a reversal in wind direction (with east winds this is probable).

II. When in any quadrant of a depression, to climb in order to reach a level where the wind tends to flow away from the centre and thus gain the periphery by flying with such winds.

Experienced pilots might take objection to methods *A*., I. (*b*) and *A*., II. (*b*) on the grounds of analogy with the characteristics of the centre of the typical tropical cyclone, but a careful study of weather charts reveals the fact that in a great proportion of the most intense depressions passing over the British Isles there exists a considerable area of light winds in the centre.[4] Further, a glance at the mean values for the rate of travel of depressions across these islands as calculated from the analysis of the twelve years, 1906-1917,[5] should assure the pilot of the ability of the airship to travel with the centre. The mean rate of travel is calculated as 22 miles per hour, but for practical purposes it must be emphasised that in individual cases there is wide divergence from that mean over a range of velocities from zero to 80 miles per hour. This wide divergence only serves to illustrate the futility of generalisations and of the formulation of any set rules, and supports the writer's contention that in practice each case must be treated upon its own peculiar characteristics. It must, therefore, be understood that in the selected examples dealt with in detail below, although they may be considered typical, it would be more accurate to describe them as the most simple in that on comparison with a series of isobaric charts many of the latter will prove exceptions to the type and infinitely more complex.

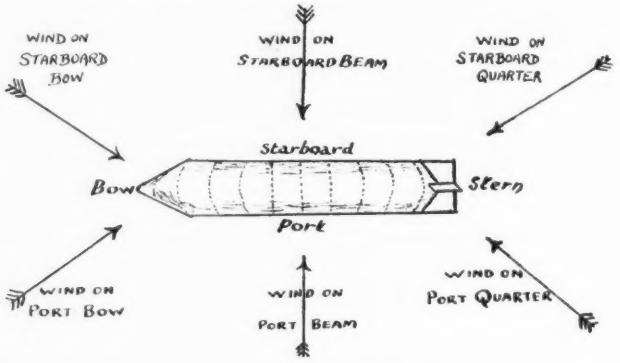
In the case of a moving depression, the plotting of a course for the airship becomes complicated by the movement of the former. The first procedure is

[4] *Examples*.—The period between October, 1919, and April, 1920, chosen at random, gives eight instances, *vide* 7h. synoptic charts on the following dates:—27th October; 19th December; 3rd, 11th, 30th January; 15th March; 16th, 20th April.

[5] Silvester, *Q.J. Met. Soc.*, Vol. XLV., No. 190, page 171.

to plot on a blank map of the area a series of points representing the position of the centre of low pressure at regular intervals of time. These points are approximate as they are interpolations between the positions as given on the track of depression charts in the monthly weather report, and it has been assumed that both velocity and direction remained constant between the times of construction of the synoptic charts from which the depression tracks are compiled. Next, a tracing of the depression is taken and at numerous places in all its quadrants is recorded the velocity of the gradient wind computed from the usual equation[6] or measured with the special geostrophic wind scale devised for the purpose. The direction of the gradient wind is regarded as coinciding with that of the isobars. The tracing is now superposed on the blank map of the area. Given the velocity and direction of wind and airship the course of the latter is plotted hourly with the aid of the simple triangle of forces (familiar to navigators) in which the resultant represents the track of the ship. The tracing is shifted along at the end of each operation so as to keep the centre on the correct point on its track. It can be objected that the numerous approximations that enter into this method of procedure preclude the possibility of accuracy. When it is realised, however, that in practice far greater errors commonly enter into the construction of the isobaric charts, such as those due to small observational errors in barometer readings and in the interpolation of the isobars, no apology for such approximation should be necessary.

For the sake of brevity the usual nautical language is employed in describing the positions of the airship relative to the wind. The following sketch indicates the meaning of the terms used and is included for the enlightenment of the "landlubber" with apologies to all seamen.



As but scanty information is available relating to the weather traversed by the airship on the various courses on account of the fact that a greater portion lie over the sea, it is practicable to denote on the tracing of the isobaric chart only approximately the areas of weather that render the navigation of airships difficult. Thus the parts heavily stippled represent roughly the areas over which rain, snow, or other precipitation, including fog and mist, occurred at the time

[6] $y/\rho = 2\omega V \sin\lambda \pm (V^2/R) \cot\alpha$

where y = pressure gradient
ρ = density of air
ω = angular velocity of earth
V = velocity of air
λ = latitude
R = radius of earth
α = angular radius of small circle

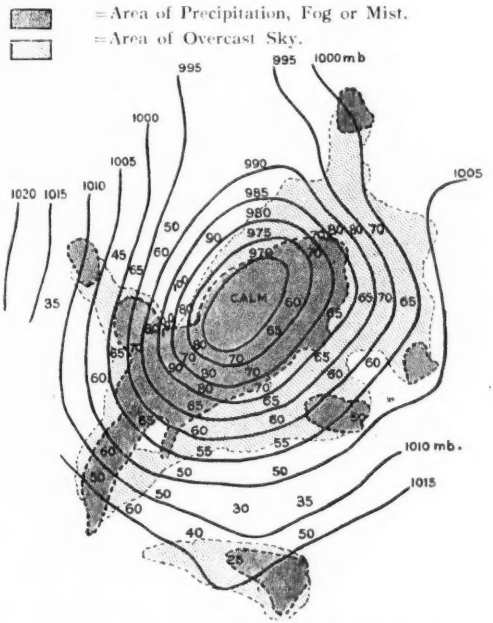
due to Ferrel, Guldberg and Mohn, *vide* Sir Napier Shaw, *Forecasting Weather*, pp. 42-5

of construction of the chart. The light stippling denotes the areas over which the sky was overcast at that time; but, unfortunately, the records of the daily weather reports for this period give no information as to the cloud height, so that these areas cannot be assumed to have been overcast by low cloud, although by analogy with the typical cloud distribution in such cases it seems highly probable.

Example I.

The depression selected as typical of the fast moving type crossed the north of the British Isles between the 14th and 15th October, 1916. It moved in an

EXAMPLE 1.
14–16 October, 1926.
Fast-moving Low. Rate of Movement 40 m.p.h.

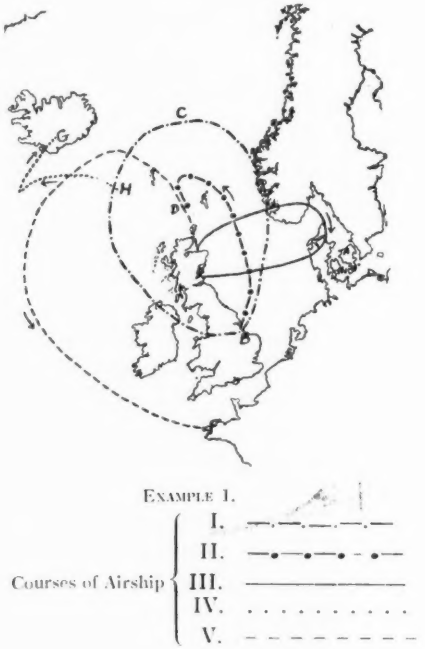


Figures between Isobars = Velocity of Gradient Wind in m.p.h.

Scale :—1 : 2×10^7

E.N.E. direction at a mean velocity of 40 miles per hour and was accompanied by gales over Ireland, Scotland and the North Sea, the surface wind reaching force 9 at Blacksod point and force 10 at Skudesnaes. The gradient wind as measured from the barometric gradient (indicated on the chart by figures between the isobars) reached a maximum of 100 m.p.h. in the rear of the disturbance. A number of trajectories of the gradient wind have been constructed in this example only (shown upon a separate map) the arrows denoting the direction of movement of the air, whilst the figures give the time at which the air was over the points marked by the arrows. These trajectories serve to show the course of an airship if it became disabled so as to be no longer dirigible.

Course I.—It is assumed that a ship set out from a base B, in the East of England, in reasonably quiet weather, at 7 a.m. on the 14th, and proceeded N.N.E. on patrol; but that two hours later it was caught in a southerly wind current, whose velocity not only prohibited its direct return to B but also its safe landing at any other point in this wind. The pilot must therefore regain his base by an indirect route involving the circumnavigation of the depression. It is suggested that he cruise at a speed of 40 m.p.h. with the wind one point

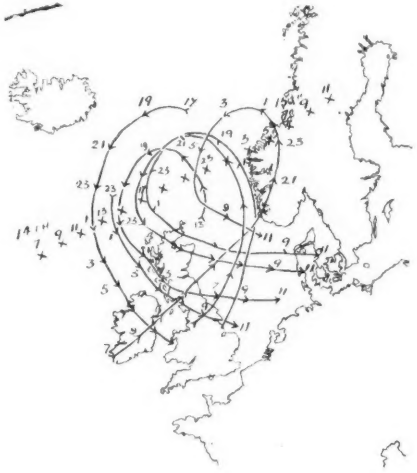


on his starboard quarter. In eight hours' time he should reach C, when owing to his favourable position to windward of his base he can reduce his speed almost to zero and drift with the wind. After 18 hours of drifting thus he should reach N. Wales in a current of approximately 30 m.p.h., in which he should be able to navigate with ease and to land the airship in safety at B two hours later in a surface wind of less than 20 m.p.h. It is obvious that the airship could traverse a similar course in far less time by maintaining its cruising speed instead of drifting and by slight alteration of course from time to time. In such case, however, the airship would reach its base B before the disturbance had passed when the wind would be too strong; so that the ship would be unable to make a safe landing and would again be blown to leeward. It is therefore necessary in this case to spend the above time in drifting. Duration of flight = 28 hours fuel for ten hours cruising speed consumed.

Course II.—It is assumed that the airship is caught at the same point as in Course I., but that the only available base is at D, in the Shetlands, over which the centre of the depression is forecasted to pass. If provided with good synoptic charts at frequent intervals he will be able to form an estimate of the dimensions of the area in the centre where he may expect light winds and also

to calculate approximately the time when the centre will reach D. In this case the airship must reach D not earlier than eight hours and not later than twelve hours from the start. In order to do this it is suggested that he steer a course with the wind on the port beam, maintaining a cruising speed of 40 m.p.h. He should thus gain the central area of light winds just when this area has reached D, so that he will have four hours in which to locate his landing ground, which will probably be obscured by low clouds or rain, before being overtaken by the approaching northerly winds of gradient velocity of 70—100 m.p.h. in the rear of the low centre.

If whilst pursuing such a course, the pilot was pressed for time and discovered by calculation that by flying in the gradient wind at full speed he would not reach the centre until it had passed his base; it might be pointed out that by descending to a lower level he ought to be in a position to reach the centre more rapidly by utilising the incurvature of the wind, due to friction near the surface. It should, however, be remembered that such a course would be dangerous (except over the sea) owing to the strong turbulence of the lower layers flowing over an uneven surface at high velocity.[7]



EXAMPLE I.

Gradient Wind Trajectories.

Centre of Depression at 2 hr. intervals 7 x 9 x 11 x

Course III.—The airship is assumed to be 100 miles to leeward of the base at E at 7 a.m. on the 14th, with the gradient wind increasing to 65 m.p.h. from the S.S.W. The pilot now endeavours to regain his base by the direct method of running the ship at full speed, keeping it head on to the wind—a mode of procedure that would naturally appeal to the dogged spirit of a British airman. In 24 hours' time it will be observed that he is likely to have gone astern 350 miles, whilst at 1 p.m. next day, after fighting for 30 hours against the gale,

[7] G. I. Taylor deduces from data published by J. S. Dines, in Technical Report of Advisory Committee on Aeronautics, p. 216, that the diameter of an eddy formed in a wind velocity of seven metres per second at the surface is greater than 40 metres. *Phil. Trans. Roy. Soc.*, Series A, Vol. 215, p. 22.

he will have been driven back about 500 miles E.N.E. of his base. At this time he should be encouraged by noting that although he has been badly defeated by the wind, he has improved his position relative to the centre of the low and has consequently reached a sector in which the winds are moderating. By 1 a.m. on the 16th he should be 350 miles E. of the base with the prospect of encountering a breeze of not more than 15 m.p.h. during the rest of the voyage. Upon this calculation his project is doomed to failure, as when within three hours of E his 48 hours' fuel supply will fail—the time required being estimated at 51 hours at full speed. It would not appear, therefore, that this course is to be recommended unless the rate of travel of the depression is greatly in excess of the rate at which the airship is driven astern.

A more futile alternative for the airship starting from the unfavourable position postulated in Course III. is the adoption of a course at full speed with the wind on the starboard beam with the object of gaining the outer edge of the disturbance. He will find that his course over the ground will be in a direction identical with the movement of the low and will exceed its rate of movement by only 15 m.p.h. Thus after ten hours at full speed he will reach a region directly in the forefront of the depression where the southerly gradient wind is but 30 m.p.h. If he now alter course to four points to starboard to gain a more favourable position in the S.E. quadrant in a few hours, he will be in a position relative to the low centre identical with his starting point, but geographically at some point over the Baltic Sea, E. of Sweden, with very remote possibility of regaining his base at E before his fuel is exhausted.[8]

Course IV.—It is supposed that the point H represents the position of the airship at 9 a.m. on the 14th in the N.E. quadrant of the oncoming depression and that the only base available is one in Iceland at a point G. It is suggested that the pilot steer a course with the wind on the starboard beam and use the maximum engine power, as by so doing he will avoid the sector of maximum intensity immediately to the rear of the centre. In four hours' time he should be approximately 230 miles to leeward of G. If he now alter course so as to put the ship head to wind he should expect, although he may go astern for another four hours, that in the quieter regions further to the rear he will make headway. Thus after 16 hours from the start he ought to be only 150 miles from G, which point he should reach by 7 a.m. next day, *i.e.*, after 22 hours' flight at full speed.

Course V.—The airship becomes involved in adverse winds at a point 100 miles north of E at 7 a.m. on the 14th, and has but one base available for housing at F in Brittany. It is suggested that he attain this object by circumnavigating the depression. To accomplish this, he would turn down wind and keep a course with the wind two points on his starboard quarter, throttling down to a speed of 20 m.p.h. so as to allow the low to move past F before he arrive there. At the end of 12 hours he should be sufficiently far from the centre and to the rear to be beyond the region of dangerous winds. Now if he alter course two points to port so as to run before the wind, he should reach F in another 12 hours after a voyage of 24 hours at less than half his maximum speed. This period, however, does not represent the minimum in which he could perform this voyage, as it is seen that the base F ought to be available for safe landing eight hours earlier. At full speed, this course could be reduced to a minimum of 16 hours.

There are a number of difficulties connected with navigation in a depression quite apart from that due to the wind velocity. A few of these it might be useful to enumerate to dispel the idea that all is plain sailing when once the best course has been decided.

1. During the winter heavy snowfalls are common in the N.E. and N.W. quadrants. When the air through which the snow is falling is many degrees

[8] This alternative is not shown on the chart.

below the freezing point of water, the snow flakes are quite solid and of a powdery consistency and consequently would not be likely to settle on the smooth surface of a body moving at a high velocity. If, however, the air temperature during the snow storm be in the vicinity of 32°F. there is great danger of the snow flakes melting on contact with the envelope of the airship, which process by involving absorption of the latent heat of fusion causes partial regelation, so that the envelope rapidly becomes encrusted with a sheet of half melted ice. This ice sheet is liable to accumulate so as to render the airship heavy to a degree far beyond compensation by the release of water or other ballast. Should an airship become involved in a storm under such conditions only two courses appear reasonable :—

(*a*) To descend nearer the surface in the hope of finding a stratum of air at a temperature well above freezing point which will rapidly melt the ice on the envelope. Thus assuming the vertical temperature gradient to be normal at 1°F. per 300 feet, it would hardly seem advisable to adopt this course unless he were over 3,000 feet above the surface at the time of encountering a snow storm at 32°F.

(*b*) To ascend rapidly in the hope of either reaching

(i) The upper limit of the snow cloud.

(ii) An altitude at which the temperature was well below the freezing point. Thus assuming that the airship encountered the storm at a height of 1,500 feet and a temperature of 32°F., with a normal lapse rate, it would have to climb to 4,500 feet to find an air temperature 10° below the freezing point. To reach the upper limit of the lower cloud layer he might have to climb quite twice that altitude.

2. Thick weather extending over large areas, especially in the forefront of a depression, renders it necessary to steer a course by compass alone. The uncertainty of knowing the exact position after several hours upon a compass course leads to further complication due to the geographical variation of magnetic declination. When it is realised by a cursory inspection of an isogonic chart that corrections over a range of 20° would be necessary in a flight between Denmark and Iceland, it must be agreed that the pilot should have a check upon his position from time to time. This difficulty might be overcome by direction finding wireless telegraphy, but would require greater accuracy than was found possible in its experimental stages during the war.

3. The considerable range in pressure experienced in an intense low pressure system would cause the pilot some uncertainty as to the accuracy of his aneroid altimeter readings. Thus, suppose a ship to leave B, on the outer edge of the cyclone, with the pressure at 1,005 millibars and to land at D in the centre of low pressure with the pressure at 970 millibars, the ship's altimeter would read nearly 1,000 feet too high, so that the pilot from above might mistake a low stratiform cloud at 1,000 feet for a thick ground fog and might thus despair of finding a base which in reality was clearly visible below the low lying clouds. Should the airship take a course in the reverse direction from low to high pressure in thick weather, with a mountain range to traverse near the end of the course, an unadjusted aneroid might result in a disastrous collision with the summit of the range. With transmission at frequent intervals of his position and of the data for constructing synoptic charts this difficulty could be overcome.

4. The passage of an intense depression, especially when it develops a V form on its southern periphery, is frequently accompanied by a line squall. This phenomenon occurs approximately on that part of the trough line which divides the S.E. from the S.W. quadrant. It is coincident with and apparently caused by the upward displacement of a warm and damp current of equatorial origin by

a relatively cold and dense polar current. Violent vertical currents (the components of eddy motion or convection on a gigantic scale) are produced which are liable to cause structural stresses on sectors of the ship not designed to stand such, whilst lightning and hail frequently augment the dangers. From observation of the clouds during the passage of line squalls it would appear that the most violent motion is confined to the lower regions of the troposphere. Hence it is suggested that upon the first warning of a line squall the pilot should climb to about 10,000 feet, where he might reasonably expect only a reduced reflection of the disturbance below.

5. It will be observed that the courses are set with relation to the wind direction. Hence it must be assumed that the pilot has this information transmitted by wireless. He will, no doubt, wish to test the accuracy of this information, especially when it is derived—not from direct observation—but indirectly from calculation of the barometric gradient. There is no difficulty in carrying out observations of wind velocity and direction from an airship when the surface is visible. When, however, the surface is obscured by fog, mist, or some form of precipitation, the solution to the problem presents considerable difficulty. When the course lies over the sea it is suggested that the wind direction could be obtained by the following procedure:—

The airspeed of the ship is reduced to zero. A float attached to the ship by a light wire cable is dropped into the sea. The direction in which the cable runs out from the ship, after the float has reached the water, will coincide with the wind direction. By means of a simple trigonometrical calculation, a rough estimate of the velocity could also be obtained by observing the rate at which the cable ran out after the float reached the water. The latter calculation would require correction for

(*a*) Vertical movement of the airship if not in equilibrium.
(*b*) Direction and velocity of the marine current in the locality.

When flying over land, a modification of the above method might be attempted provided that the course lay over a sparsely populated area. It would mean the loss of a grapnel or similar device after each observation.

Example II.

This depression travelled from South Ireland on the 27th October, 1916, to South Scotland on the next day at a mean velocity of 14 miles per hour. At 7 a.m. on the 27th it caused gales at the Scilly Islands and Holyhead—at the former station the velocity was reported as force 9 on the Beaufort scale and this gale apparently persisted throughout the day and probably reached force 10 during the afternoon, assuming the usual diurnal variation. At the evening hour of observation gales were reported at Portland Bill (from S.W.) and Blacksod Point (from N.E.) in addition to the above mentioned localities. After 24 hours the intensity seemed quite unabated, as gales still raged at Portland Bill, Dungeness, Spurn Head and Cape Gris Nez at 7 a.m. on the 28th. It is from observations at this hour that the tracing utilised in this example is derived. The central area of the depression, as indicated by the 980 millibar isobar, showed only a slight diminution in size during the 24 hours. The distribution of precipitation and cloud appears normal except for a narrow strip of fair weather existing along the south coast of England in a position S.E. of the centre. This disturbance may therefore be regarded as typical of a slow moving though intense low pressure centre.

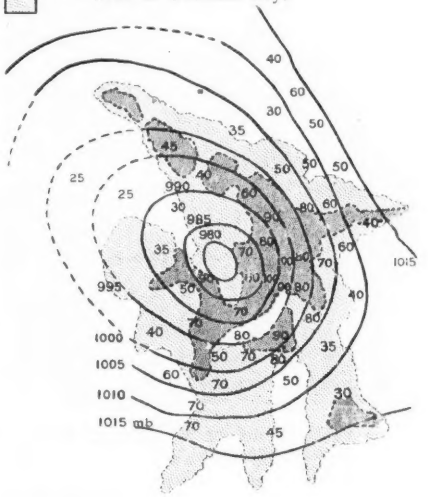
In the three courses plotted in this example it is assumed that the airship is caught in a southerly gradient wind of about 80 m.p.h., about 50 miles to leeward of B at 7 a.m. on the 27th October. It will be at once apparent that with fuel limited to 48 hours it is futile to attempt to regain the base B because on account of the slow movement of the low, the high winds will persist over

that point for more than 48 hours. Thus, the following two courses discussed in Example I. may be eliminated in dealing with this depression.

1. To fly head to wind and fight a long battle until the storm has passed.
2. To fly down wind or with the wind on the starboard quarter in order to circumnavigate the low and arrive at B after its passage.

Course I. assumes a base at F over which the centre of the cyclone is forecasted to pass 24 hours after the commencement of the flight. It is suggested that the pilot steer a course with the wind on the port beam when after nine hours at cruising speed he ought to find an area of light winds at the centre, which at that time should be off the east coast of Ireland. During the following 15 hours he will have to maintain this central position with great accuracy as in this case the area of light winds is relatively small. At the end of 24 hours he should be able to effect a safe landing at F. This course is only to be commended as a last resource.

EXAMPLE 2.
27–28 October, 1916.
Slow-moving Low. Rate of Movement 14 m.p.h.
=Area of Precipitation, Fog or Mist.
=Area of Overcast Sky.



Figures between Isobars=Velocity of Gradient Wind in m.p.h.
Scale:—1 : 2×10^7

Course II.—The pilot desires to extricate his ship from a similar position to that postulated in Course I., but with a place of refuge at D in the Shetland Islands. By steering a course with the wind four points on the starboard quarter, the pilot will rapidly gain the periphery where the gradients are less steep. In about eight hours' time, at cruising speed of 40 m.p.h., he should be in the vicinity of D in a gradient wind of 35 m.p.h. He should have a detailed knowledge, before commencing the course, of the local surface conditions at D so that he will be able to make a fair estimate of the ratio between gradient and surface wind. Unless the landing ground be very exposed he might expect a surface wind varying between 15 and 25 m.p.h., according to the time of the

day. As it will be 3 p.m. when he arrives he may expect a maximum velocity accompanied by maximum gustiness at the surface and therefore, unless the wind is forecasted to increase, it would be advisable to delay his arrival till dusk. The isobaric chart shows that no increase in gradient wind is anticipated before midnight that day. Hence, a similar course at reduced speed seems more prudent.

The relation between the velocity of the surface wind and that of the gradient wind is a subject of primary importance to the handling of an airship on the ground, but is one to which too little attention has been paid. A detailed analysis of these elements has been made for an airship station at Mullion, in Cornwall,[9] in which two sites have been compared, but, unfortunately, the records available at the time of making this analysis covered too short a period to furnish reliable means. These two sites, although little more than one mile apart—the one partially sheltered in some directions—the other well exposed at all points of the compass, clearly demonstrate the extent to which the surface wind is modified by obstacles.

The variation in the ratio, gradient velocity/surface velocity, is dependent upon the following factors:—

(*a*) Exposure including—

(i.) Orographic features such as mountains, valleys, lakes.

(ii.) Local obstacles on the surface such as woods, towns, large buildings.

(*b*) Direction and origin of the wind. Thus it is found that a southerly current of equatorial origin, such as that experienced in the forefront of a depression, traverses a surface with less loss of velocity due to friction than a northerly current with a polar trajectory; because the first has usually an upward component, but the second the reverse.

(*c*) The local time of the day—thus surface friction appears to reach a minimum in the afternoon and a maximum in the early morning at or before dawn.

[9] Silvester, "Weather Conditions at Mullion, Cornwall," *Q.J. Met. Soc.*, Vol. XLVI., No. 195, 1920, pp. 251/2.

(*d*) The season of the year. The colder the surface or air the greater is the friction.

(*e*) The sign and value of the lapse rate near the surface—for example, a negative lapse rate, *i.e.*, when the temperature of the air increases upwards—tends to increase the friction of the surface wind and hence to increase the ratio. This factor is probably involved in the seasonal and diurnal variations.

Furnished with an analysis on these lines for the station for which the pilot was bound, the latter should have no difficulty in deriving a forecast of the surface current from the value of the wind at 1,500—2,000 feet.

Ideal conditions for landing during a strong gradient wind should be realised on a plain, to leeward of an escarpment clad with forests, in a northerly wind, at the rear of a depression in winter, at dawn, after a cloudless night. By analogy with a number of individual cases recorded at Mullion, in none of which were all the above conditions satisfied, a ratio value of over three might be safely predicted in such ideal circumstances. Thus, for example, suppose a surface wind velocity of 20 m.p.h. to be the safety limit for handling an airship on the ground, a pilot should be able to land without difficulty when the wind at 2,000 feet was 60 m.p.h.

Course III.—The base to which the pilot desires to fly is at a point C, near Biarritz in the South of France. He starts as before from a point to leeward of B. The most circuitous route seems advisable. It is suggested that the ship cruise at 40 m.p.h. with the wind astern. After about 13 hours the course should be altered four points to starboard, when after 11 more hours the ship should reach the vicinity of C, having flown a distance of over 2,000 miles, of which about 1,600 would be over the Atlantic. The gradient wind over C will be 30—40 m.p.h. from the west at 7 a.m. on the 28th October, when the ship is ready to land; so that the chances are in favour of a safe landing in a wind of less than 20 m.p.h., considering the time of the day. A more direct course was plotted[10] in which the airship had to navigate the S.E. quadrant of the low. It was found that by running for four hours with the wind on the starboard beam, then altering course to bring the wind four points on the starboard bow, after eight hours the ship should be over N. Denmark, and in another similar period over the north coast of Germany, about 100 miles E. of Kiel, whilst after 40 more hours the ship will be due to reach C. This course is thus seen to be unsatisfactory as it requires 60 hours at full speed and navigation over enemy country.

Example III.

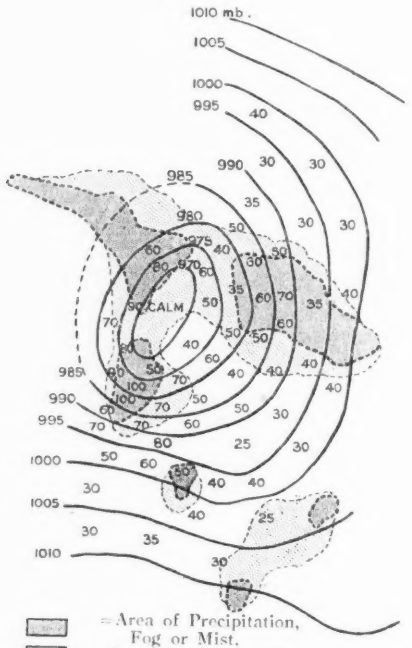
This is an example of a stationary depression with its centre over the Atlantic, just north of Scotland (marked by a black cross on the course chart). This disturbance was firmly established at 7 a.m. on the 6th November, 1916, when it consisted of a simple primary with only a faint indication of the formation of a secondary S.E. of its centre. A study of the area of precipitation seems to show that the forefront of the disturbance, should it commence to move, would be on the north side. The most unusual feature is the patch of fair weather extending to the centre from the S.E. quadrant. In 48 hours' time a secondary having developed on the southern side with its centre off the coast of Yorkshire, it was found necessary to utilise a second tracing of the isobaric distribution at seven hr. on the 8th November in plotting the courses. The later map reveals a wide extension of the area of precipitation to the S.S.E., roughly along a line drawn through the two centres, but there still remains a patch of fair weather to the S.E. of the primary centre, although this area is much restricted. A similar though diminutive area occurs immediately to the south of the secondary centre.

[10] Not shown on the course chart.

As this depression is stationary it would appear that, on the assumption that the airship became involved in any quadrant except that in which the secondary was in process of formation, and that the ship was in some position many miles to leeward of the base for which she was bound, the straightforward method of flying into the wind would not be practicable. As, however, the gradients are not so uniformly steep as in the two previous examples, there might be locally a prospect of success by this method, particularly towards the end of the 48 hours period when the depression showed signs of filling up.

EXAMPLE 3A.

7 a.m., 6 November, 1916. Isobaric Chart. Stationary Low, Developing Secondary on South Side.



Figures between Isobars=Velocity of Gradient Wind in m.p.h.

Scale:—1 : 2×10^7

Course I. assumes the airship to be at a point 100 miles to leeward of a base B at 7 a.m. on the 6th November, with another base available at F in the Shetlands, in the vicinity of the primary centre. It is suggested that the pilot, who will have received information of light breezes prevailing at F, steer a course with the wind on the port beam when he should reach F within seven hours at cruising speed. The pilot has now two alternatives:—

(1) Of being housed at F until the disturbance disperses or moves away.

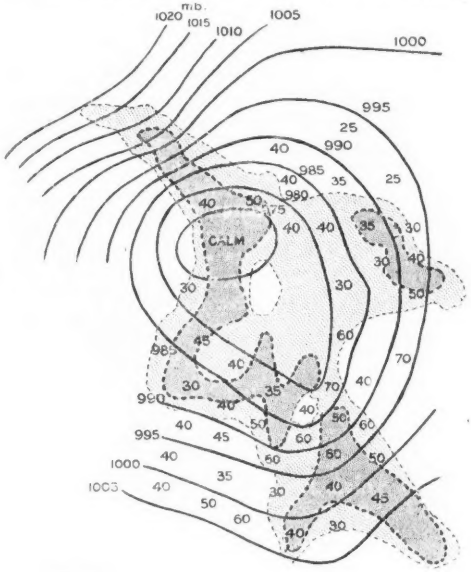
(2) Of mooring out for about 30 hours until the secondary on the southern side of the primary has created an area of light indefinite breezes between the two centres. This area will include the base B to which the pilot will now be

able to return. In making this flight, the pilot is advised to assume the influence of the primary to be predominant and so to make allowance for moderate westerly winds on the course from F to B. It is suggested that he steer for a point about 100 miles W. of B and approach the base from that quarter. This flight should take about eight hours at cruising speed.

Course II. assumes that it were possible to establish a base at a point C on the S.E. coast of Greenland, such a point being the nearest in a N.E. direction for a safe landing on the periphery of the depression. The ship is assumed to be in a similar position at 7 a.m. to that in Course I. The course shown on the chart would be followed by flying at cruising speed with the wind four points on

EXAMPLE 3B.

7 a.m., 8 November, 1916. Isobaric Chart. Same as 3A after Development of Secondary.



= Area of Overcast Sky.

= Area of Precipitation, Fog or Mist.

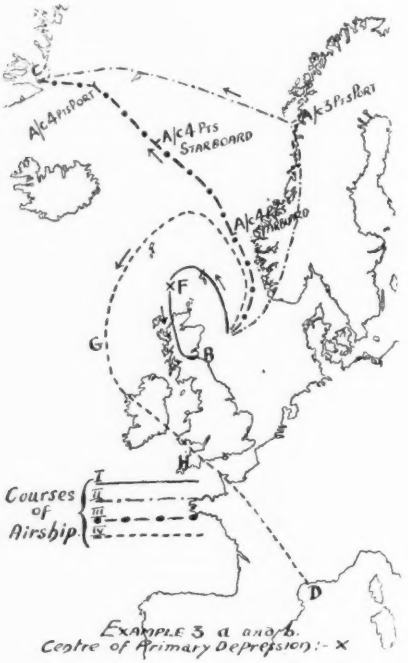
Figures between Isobars = Velocity of Gradient Wind in m.p.h.

Scale :—1 : 2×10^7

the starboard quarter. The ship should reach the Norwegian coast within three hours and then have to fly for six hours over a mountainous part of that country, during which the altitude would have to be increased to over 8,000 feet to avoid some of the highest peaks in Norway. The prospect of violent turbulence, due to the surface configuration, could be confidently expected. At the end of 13 hours, when off the Lofoten Islands, the course should be altered three points to port, thus bringing the wind almost astern. After 28 hours flight at cruising speed the ship should be at C and able to land in a moderate N.E. wind which would be increasing.

Course III. is a modification of Course II. in which precisely the same starting conditions are postulated. It is designed to obviate the prolonged flight over

Norway and also to accomplish the voyage in less time to minimise the risk of the winds increasing at C. (It will be observed that the steepest gradient occurred in this direction at the end of the 48 hours' period, *i.e.*, at 7 a.m. on the 8th November.) The ship should run before the wind for five hours, then alter course four points to starboard and thus fly with the wind four points on the starboard quarter for eight hours. Now he should again alter course four points to starboard and run thus for six hours with the wind on his starboard beam. A further alteration by four points to port should bring the ship to C, after a total flight of 23 hours at cruising speed. This means a saving of five hours as compared with Course II. and the prospect of lighter breezes for effecting a safe landing at dawn on the 7th November.



Course IV.—The airship at 7 a.m. on the 6th November is in the same predicament as in the previous courses and wishes to proceed to a base D on the Gulf of Lyon, on the S.E. margin of the cyclone. The following procedure is suggested as most favourable. By flying at cruising speed (40 m.p.h.) throughout the course, and with the wind for 12 hours, after a circuitous course three parts round the centre, the ship should be approximately at G, where the course is altered eight points to starboard, and carrying on for five hours with the wind on the starboard beam, should reach a point H. At this point it will be beyond the region of maximum gradient winds. At H the course is altered three points to port in order to arrive at D, after a further voyage of nine hours' duration. The course involves a total duration of 26 hours at cruising speed. The airship will be ready to land at D at 9 a.m. on the 7th November with a westerly gradient wind of 25 m.p.h. increasing.

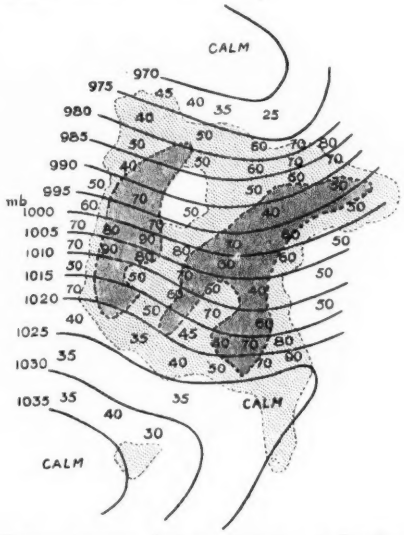
Should the pilot at the commencement of this flight receive a forecast of the formation of a secondary in the southerly quadrant, he will realise that the area between D and the secondary centre is liable to become the zone of steepest pressure gradient and subject to a line squall. It would therefore seem the wiser course, if there is no alternative base to D, to arrive there at the earliest moment. A similar course at full speed could be accomplished in approximately 22 hours, involving a landing at 5 a.m. (normally the most favourable period during the 24 hours, when the ratio gradient wind velocity/surface wind velocity is at a maximum). In the particular case under examination, although the formation of the secondary was attended by a considerable increase of wind in this sector, the development in the direction of intensity took place on the N.E. side of the primary. Moreover, the base D was too far south to be more than slightly affected by this increase in gradient.

EXAMPLE 4.

7 a.m., 27 November, 1917. Isobaric Chart.
Westerly Type.

= Area of Precipitation, Fog or Mist.

= Area of Overcast Sky.



Figures between Isobars = Velocity of Gradient Wind in m.p.h.

Scale :—1 : 2×10^7

Example IV.

The weather chart at 7 a.m. on the 27th November, 1917, is a fair example of a persistent type of pressure distribution resulting in our prevalent westerly winds. It is seen to consist of a depression of considerable magnitude, whose northern margin is situated somewhere in the neighbourhood of Spitzbergen, whilst its influence extends southward as far as the Bay of Biscay. Whilst the centre remained practically stationary, there was, as is usual, along the isobars over the British Isles an undulose movement simulating the mode of progress of the caterpillar. Apart from local orographic causes, it is only to these fast moving minor sinuosities of the isobars that we can attribute the irregular

distribution of precipitation found in this parallel arrangement of isobars. Westerly gradient winds of over 60 m.p.h. velocity are deduced from the pressure gradient over a belt 1,000 miles in width from N. to S., whilst locally in this region the velocity attains 90 m.p.h. In this case the type persisted for four days subsequent to the 27th November. It cannot be assumed that the isobars of 980, 985, 990 millibars and those contiguous in the direction of higher pressure follow the trend of the 975 millibar isobar if continued eastward, because another low centre existed simultaneously over N. Europe. Westerly gales were reported from Castlebay and Stornoway in the outer Hebrides, from Malin Head and Liverpool on the morning of the 27th, whilst at Skudesnaes on the west coast of Scandinavia and at Bornholm in the Baltic a surface force of 10 on the Beaufort scale was reported at the same hour, thus indicating that the gradient wind measurements referred to above are probably correct.

In plotting the following courses it is assumed that the pressure distribution remains consistent throughout. It must be emphasised that the probability of an airship becoming involved through lack of foresight in such a weather type is remote, as this type is one which forms slowly and is therefore simple to forecast.

The idea of circumnavigating the centre with the object of approaching a base from windward does not appear practicable on account of

(i.) The vast size of the depression.

(ii.) The persistence of the same.

Course I. assumes the airship to be at a point B on the east coast of England at 7 a.m. on the 27th November, being drifted astern in a wind of 60—70 m.p.h. at 2,000 feet. The pilot desires to run southward for safety to the nearest base C beyond the area of high winds. The course plotted demonstrates how impracticable is this method. After running for 12 hours at 40 m.p.h. with the wind on the starboard beam he should find himself over a hostile part of Europe at some point about 700 miles east of F, after travelling for most

of the time over the enemy's country. At this point he will have to navigate a course over the Alps, which will mean increasing his altitude to over 15,000 feet.

Course II. seems almost as impracticable as Course I. It assumes the same point and time of commencement, but with the objective at D, a floating mooring base 500 miles N. of Scotland. Flying at cruising speed for 12 hours with the wind on the port beam should bring the ship to a point far to leeward of D, over the Baltic Sea off the coast of Finland. He should now have reached the border of an area of light and variable winds existing between the two centres. If the pilot now steer direct for D he should continue in this neutral area for five hours. Now he should find a belt about 150 miles wide where southerly winds of velocity up to about 30 m.p.h. are expected. If he continue on the same course he should reach the central area of indefinite light winds after four more hours, but having drifted about 100 miles N. of a straight course to D. From this point he should gain D in ten hours time. This involves a total flight of 31 hours at cruising speed and includes the navigation of the Scandinavian mountain range, with the prospect at the end of mooring out for a considerable length of times awaiting amelioration of the weather to the south.

If it is assumed that there are no bases available outside the belt of adverse winds, it would appear that as a last resource the pilot mgiht steer up wind for the nearest base, flying as low as possible to take advantage of the diminution of velocity due to surface friction and to utilise detailed local forecasting of the movements of sinuosities in the isobars, and it would then be his endeavour to reach a base simultaneously with the arrival of a divergence in the isobars, when he might reasonably expect a temporary decrease in wind velocity sufficient to enable him to land the ship safely.

Example V.

The pressure distribution existing at 7 a.m. on March 4th, 1917, is taken as an illustration of the southerly type which is liable to occur in the winter and early spring, when the Eurasian winter high pressure encroaches westward so as to dominate the weather over the British Isles. The type usually persists for a number of days. The main area of precipitation appears to coincide approximately with that which would be anticipated on the assumption of the theory of convergent streamlines of air.[11] The minor patches of precipitation seem due to orographic features or local irregularities in the isobars. Gales from between S. and E. were the characteristic feature on the morning and evening of the 4th, whilst 24 hours later the reports show no abatement in the velocity of the winds. The area involved by these high winds embraced Scotland, Ireland and the N.E. of England. The weather was reported as squally over a wide area, including Scotland, Ireland and S.W. England, and the squalls were rendered more dangerous to lighter-than-air craft by snow and hail in Scotland and the development of a thunderstorm with hail in S. Ireland. Over the latter district pressure gradient measurements indicate a velocity at 2,000 feet of 100 m.p.h. The centre of low pressure of this system drifted in the course of three days to the north of Spain, with a consequent transformation to an easterly type.

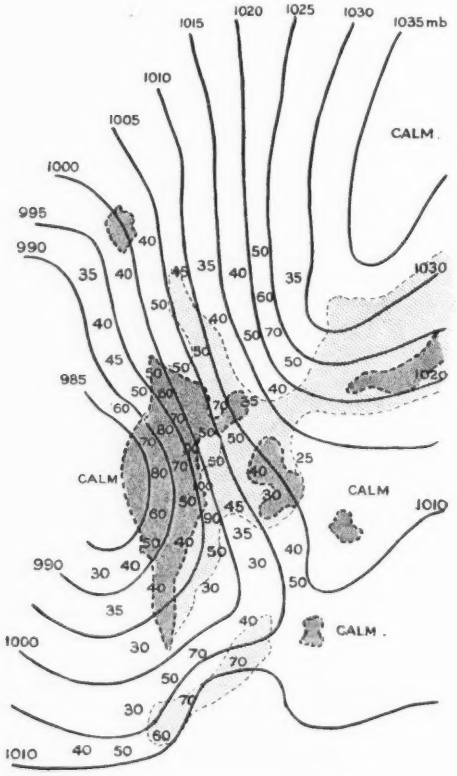
It is obvious that an airship involved in such wild weather conditions is faced with a difficult problem. Complete circumnavigation of the vast low pressure system, of which the straight isobars over the British Isles form the western half, does not appear practicable on account of

1. The persistence of steep gradients over the area.

[11] W. N. Shaw and R. C. K. Lempfert, "Life History of Surface Air Currents," M.O. 174, 1906, pp. 18-20.

2. The absence of reliable information as to its extent in a westerly direction.
3. The probability that its dimensions are too great for the capabilities of the airship. (In this connection it may be noticed that given a peripheral gradient wind velocity of 60 m.p.h. the airship, with 48 hours' fuel supply and flying with the wind, could circumnavigate a circular low pressure area of 1,750 miles diameter.)

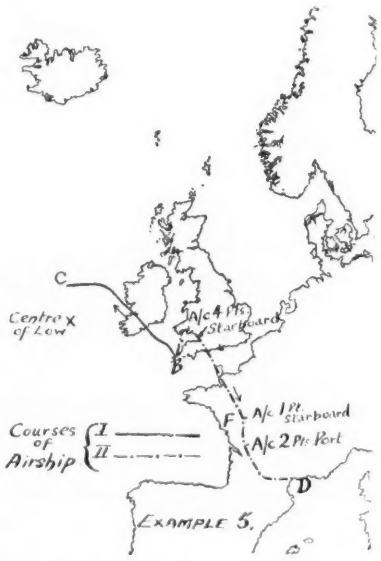
EXAMPLE 5.
4 March, 1917. Isobaric Chart.
Southerly Type.
Figures between Isobars = Velocity of Gradient Wind in m.p.h.



Course I. assumes the airship to be flying in the gale at B, off the coast of Cornwall at 7 a.m. on the 4th March, and a vessel to which the airship can moor lying at C, 200 miles west of Ireland. This mooring vessel would be equipped with wireless and would advise the captain of the airship before he commenced on the course that the weather conditions were favourable for handling the ship

at the mooring post. It is suggested that the pilot set a course with the wind on the port beam. In six hours time he should run clear of the dangerous winds and in two more hours be able to moor out in light winds at C. Such a course might be advisable if the central area of light winds were stationary and of considerable extent, but this is by no means usual in such a type of pressure distribution. The strong gradient is frequently maintained by a series of low centres following in close succession along parallel S. to N. paths.

Course II. assumes the airship to be in the same position at the same time as in Course I., and the existence of a suitable base at D in the Riviera. It seems feasible to attempt to reach D, provided that the anticyclone over Scandinavia is predominant, and that consequently if any movement on a large scale is forecasted it will be in a westerly direction. It seems advisable for the pilot to extricate the ship as soon as possible from the strong winds at B. By setting a course with the wind five points on the starboard bow, he should find



himself in a 45 m.p.h. current to the east within two hours, but in a position 100 miles more distant from D. He should now alter course so as to bring the wind one point on his starboard bow and carry on at full speed for 27 hours. Then it would be advisable to alter course one point to starboard to avoid a current of 50 m.p.h. N.W. of D. After three hours on this course he should be clear of this danger and he should then alter course two points to port, when, after four more hours, he should be west of D and clear of the region of strong winds. He may now steer direct for his base, which he should reach four hours later at cruising speed and make a safe landing in a light breeze. The duration of this flight is 34 hours, of which 30 are flown at full speed of 55 m.p.h., the remaining four at 40 m.p.h.

Supposing a nearer base to be available at F, near Rochefort in the Bay of Biscay, the airship ought to be able to reach this in 29 hours, on the same course as above, with the prospect of making a risky landing in a surface wind of about 20 m.p.h. at noon, when the gusty and squally characteristics of the wind would be approaching a maximum.

It will be observed that, with one exception, the climbing capacity of the airship is not utilised in the preceding examples. This is owing to the fact that at present little is known respecting either direction or velocity of the air currents above about 5,000 feet during the passage of intense depressions. The existence of outflowing currents in the upper atmosphere in the peripheral regions of cyclonic systems has indeed been proved by sounding with pilot balloons and ballon-sondes, but in those dangerous regions nearer the centre, where this information is so vital to sound aerial navigation, little information is available on account of the high frequency of low cloud and precipitation.

It is suggested that observations from aeroplanes in conjunction with anti-aircraft gunfire could furnish this valuable information. A simple scheme on the following lines might be adopted[12]:—

Synchronous observations in all sectors of a gale-producing depression are essential. Arrangements should be made to carry out a preconcerted plan from aerodromes at selected points, approximately equi-distant over the British Isles, when warning is received from headquarters of a well developed low which is forecasted to pass directly over this area. It will be necessary for the aeroplanes used in this investigation to be capable of climbing with one passenger to about 20,000 feet and with an airspeed of over 100 m.p.h. and to be equipped with—

1. Wireless transmitter.
2. Reliable altigraph or altimeter.
3. Reliable airspeed indicator.
4. An accurately set compass.

The pilot climbs until he is at least 1,000 feet above the upper limit of the lower cloud. Thus, suppose him to emerge from the lower clouds at 8,500 feet, he will continue to climb to 10,000 feet. He then signals to the gunner to fire at intervals of 20 seconds high explosive shells, timed to burst at 9,000 feet, keeping the elevation and azimuth bearings of the gun constant. The pilot can then observe in safety the bursts 1,000 feet below him. When he can see the smoke from the bursts of two or more shells he can set his machine in alignment with these, when his compass reading will give him the direction of the wind at 9,000 feet. To obtain the velocity he can follow one of the following alternatives (or preferably both, using one as the check upon the other).

(*a*) Modify his engine speed so as to maintain his position directly above the spot where the shells burst when the reading of his airspeed indicator will give him the velocity of the wind (not at 9,000 feet, but at the height at which he is flying).

(*b*) Find the mean of the times taken to traverse at a known constant air speed the distance between two consecutive shell bursts, (1) flying upwind, (2) flying downwind, when a simple calculation will give him the velocity of the wind at 9,000 feet.

The pilot then signals "cease fire" and climbs to higher altitudes and repeats the above procedure at regular height intervals so far as the higher cloud sheets permit.

A series of such observations taken over a wide area would furnish information that would prove of vital importance to aerial navigators who may, in the future, be compelled by lack of foresight, or the exigencies of war, to navigate the danger zones of low pressure areas.

[12] It is understood that experiments on these lines were conducted at an aerodrome in East Anglia shortly after this paper was written.

EXTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS

Issued by the Directorates of Technical Development and Scientific Research
(Prepared by R. T. P.)

AIRCRAFT ENGINES, FUELS AND LUBRICANTS

1 Fuels (Characteristics, Combustion and Investigations on Detonation)

Explosive Reactions in Gaseous Media, considered generally and in relation to Internal Combustion Engines. (Transactions of the Faraday Society, October, 1926.) (8.514/4040)

These transactions form a very complete summary, with bibliographies, of the present state of knowledge on explosions in Gaseous Media. The scope of the work may be appreciated from the following list of the titles of the papers included in the Transactions :—

"On the Ignition Point of Gases." (Garner.)
"Radiation in Gaseous Explosions." (Dixon Harwood and Higgins.)
"Ionisation in Gas Explosions." (Saunders and Garner.)
"Ionisation and Gaseous Explosions." (Lind.)
"A Note on the 'Uniform Movement' during the Propagation of Flame." (Wheeler and Payman.)
"The Explosion Wave in Cyanogen Mixtures and the Specific Heats of Nitrogen." (Campbell and Dixon.)
"Investigations on Gaseous Explosions, Part I., Ionisation in Hydrogen and Oxygen Explosions." (Garner and Saunders.)
"Combustion in Gas Engines." (David.)
"Explosions in Petrol Engines." (Tizard.)
The Effect of Metallic Sols in delaying Detonation in Internal Combustion Engines." (Sims and Mardles.)

Pressures of Explosion of Gaseous Mixtures at High Densities. (W. T. David, *Phil. Mag.* (7) 1, 334-337 (1926), No. 2, *Physikal. Ber.* 1854 (1926).) (8.57/4191)

Bons, Newitt and Townshend have found (Proc. Roy. Soc. A. 108-393 (1925) that the maximum explosion pressure increases more than in proportion with the initial compression of the mixture, and suggest that this is due to the increasing resistance to heat radiation.

The author shows that only a small part of the effect can be produced in this way, since the time of the explosion is too short to permit of serious loss by this means.

As possible causes he considers :—

1. Departure from Boyle's law.
2. Quicker equipartition of molecular energy in the denser medium.
3. Proportionately smaller heat loss during explosion of denser mixture.
4. Smaller dissociation in the denser mixture.
5. More complete combustion in the denser mixture.
6. Decrease of specific heat of the combustion products at higher temperature.

The author considers 1-4 negligible. The existence of the cause in 5 is demonstrated by the authors cited.

The author quotes the results of several experiments to show that the radiation of ultra-red rays by CO_2 and H_2O vapour, *i.e.*, by the principal products of combustion decreases with increasing density.

He finds this the most essential cause of the phenomenon.

Photographing the Flame of Explosives. (U.S. Bureau of Mines Note in the Journal of the Franklin Institute, October, 1926.) (8.57/4043)

The U.S. Bureau of Mines has developed a new method of measuring the speed of detonation by photographing the flame on a rapidly moving film.

Detonation, Prevention of. ("Motalin," a petrol substitute to prevent detonation, *Forschungen und Fortscritte* 2, 60, 1926. Abstract in *Motorwagen*, October 20th, 1926, p. 717.) (8.514/4059)

This fuel consists of 40 per cent. benzol and 60 per cent. petrol, with the addition of 0.2 per cent. iron carbonyl. Iron pentacarbonyl Fe $(CO)_5$ is obtained by passing CO over finely divided iron, the amount increasing with temperature and pressure from atmospheric up to 200°C. and 150 atmospheres. It is a reddish yellow oil of sp. gr. 1.46.

M.P., −20°C. B.P., 103°C. Igniting temperature, 34°C.

Decomposed by sunlight into red crystals of Fe_2 $(CO)_9$.

The exhaust is not poisonous, whereas tetraethyl lead is poisonous.

The substance itself cannot be regarded as entirely non-poisonous, but with suitable precautions there is no danger.

Anti-Detonating Compound. (D. R. Stevens, S. P. Marley and W. A. Gruse, United States Patent No. 1593040, July 20th, 1926.) (8.514/4028)

A material containing an aluminium halide is treated with a combustible organic liquid, which is then added to motor fuel to prevent detonation.

The Chemistry of Gasolines, particularly with respect to gum formation and discoloration. (B. T. Brooks, *Industrial and Engineering Chemistry*, November, 1926.) (8.51/4194)

It is pointed out that the first step in the formation of gum in cracked gasolines is the formation of organic peroxides which break up in a complex manner. The most common cause of discoloration of gasolines and kerosenes is the development of a trace of acidity. Alkalies or oil soluble bases prevent discoloration by developed acids.

Measurement of Fuel Drops in Mixtures for Internal Combustion Engines. (J. Sauter, *Zeits. Vereins Deutch. Ing.*, 70, pp. 1040-1042. Abstracted in *Science Abstracts B*, No. 346.) (8.57/4010)

Research work has been undertaken at Munich with a view to elucidating the mechanism of the production of an air-fuel mixture. Apparatus has been devised for estimating the size of the fuel particles by a method of difference of electric potential and the density of their distribution in the mixture photometrically. It is intended to extend the work to an investigation on the influence of the variations of the type of fuel used and the engine cycle employed.

Oil obtained by "Berginisation" of Lower Silesian Coal. (Abstracted in British *Chemical Abstracts*, October 15th, 1926, from *Brennstoff Chem.*, 1926, 7.) (8.511/4038)

A detailed analysis of the oils obtained from unwashed coal dust. The coal was made into a paste with half its weight of an oil obtained from a previous "berginisation" of similar coal. The total oil yield was 36.45 per cent. of the

raw coal. All the neutral oil fractions were remarkable for their low sulphur content. Attempts to prepare a satisfactory lubricating oil from the higher fractions were unsuccessful.

Anti-knock motor fuels by cracking shale oil. (Abstracted in *British Chemical Abstracts* from *Ind. Eng. Chem.*, 1926, 18, 801-802.) (8.512/4039)

Shale oil from America, Australia and France, when cracked at 120-150 lbs. sq. in. pressure, yielded petrol which was found to have anti-knock properties.

The Cracking of Petroleum. (T. G. Delbridge, *J. of the Franklin Institute*, November, 1926.) (8.512/4174)

A summary of the principles employed and the methods used in the cracking of petroleum. The "anti-knock" properties of cracked fuels are emphasised.

2 Lubricants and Lubricating Systems

Lubrication of Aero Engines. Possibility of substituting Mineral Oils for Castor Oil. (*La Revue Petrolifere* Nos. 182 and 183.) (8.41/4061)

A number of mineral oils for lubricating purposes have been experimented upon. The technical director of the Air Union has stated that mineral oils of good quality are suitable for the lubrication of most, but not all, the engines used in air transport, provided an oil tank with separator, an oil cooler and an oil purifier are used. Veedol extra heavy oil has been in use on aircraft of the Latecoere Co. for some time and appears to have given complete satisfaction. Mobiloil B and Texaco oils are used as lubricants on a number of U.S.A. aircraft engines.

The Determination of the Viscosity of Lubricating Oils. (By Dr. Sass, *Zeitschrift des Vereins Deutscher Ingenieure*, October 16th, 1926.) (8.41/4046)

The relations between the various formula employed in viscometry are discussed, and it is concluded that none of the existing methods of determining viscosity is, in practice, wholly satisfactory.

Sources of Contamination of Crankcase Oil. (R. L. Skinner, *J. Soc. of Automotive Industries*, September, 1926.) (8.44/4014)

The causes and effects of dilution are discussed and methods of separating out the contaminating material by filtration and evaporation are described. Prevention of dilution is said to have doubled the life of the engine and improved engine performance. The recommendation is made that all internal combustion engines be provided with suitable equipment for the positive prevention of dilution.

The Oil Rectifier. (W. G. Wall, *J. Soc. of Automotive Industries*, September, 1926.) (8.42/4017)

A rectifier is described which has been designed to take out all water and to keep the diluent between four and five per cent.

3 Compression Ignition Engines

Research on Oil-Injection Engines for Aircraft. (W. F. Joachim, *Mechanical Engineering*, November, 1926.) (12.81/4173)

This paper discusses the problem of the high-speed, high-capacity oil-injection engine, and describes some of the apparatus used and some of the results obtained in the fundamental studies conducted on oil sprays injected into compressed gases by high-speed cinema photography.

Experiments on Ignition by Compression. (Note in *Automotive Industries*, October 14th, 1926.) (12.81/4049)

A comment on the results of some experiments carried out by Andre Pignot and submitted to the French Academy of Science. The experiments consisted of compressing various fuel-air mixtures with a constant compression ratio but with gradually increasing initial temperatures until ignition occurred, the minimum initial temperature required being taken as a criterion of the ignitability of the particular mixture.

It was found that the variations of the initial temperatures required for various mixture ratios are much more accentuated in the case of the aromatic hydrocarbons than for the saturated hydrocarbons. Some tests were made to determine the effect, if any, on the ignition temperature of anti-detonants. No material effect was observed.

Diesel Engines. (12.81/4021)

The following three articles, published in the *Zeitschrift des Vereins Deutscher Ingenieure*, are abstracted in *Automotive Abstracts*, October 20th, 1926 :—

(*a*) G. Eichelberg, *Z.V.D.I.*, August 7th, 1926. Very comprehensive experiments by Suzer Bros. with a variety of injection devices are reported. The advantages of pre-combustion injection and direct jet injection are discussed.

(*b*) Prof. Neumann, *Z.V.D.I.*, August 7th, 1926. It being realised that time plays a great part in the ignition process of Diesel engines, experiments were conducted to investigate what influences tend to reduce the time element. In general it was found that the time element from the moment of injection to the beginning of ignition is far greater than the time consumed in combustion. This "ignition delay" may be reduced through high air temperature through turbulence and through fine distribution. Curves are given showing how by temperature and air velocity one can change the ignition delay from infinity to zero.

(*c*) D. J. Sauter, *Z.V.D.I.*, July 31st, 1926. This article describes the methods of measuring the subdivision of oil injected in Diesel engines.

4 *Use of Light Alloys in Aircraft Engines*

Temperature Measurements of Light Alloy Pistons. (Abstracted in *Zeit. fur. Flugtecknik u. Motorluftschiffahrt*, September 28th, 1926, from *Le Technique Moderne* 18, Nr. 8.) (10.23/4029)

It was not found possible to take measurements with the engine running, but by braking the engine suddenly it was possible to take readings ten seconds after stoppage. The results show the effects of various factors on the piston temperature, amongst those examined being the effects of compression ratio, piston play, spark setting and mixture strength.

Silumin in Aircraft and Aircraft Engines. (By H. Ehlermann, *Zeitschrift fur. Flugtechnik und Motorluftschiffahrt*, October 14th, 1926.) (10.23/4037)

The use of Silumin (Alpax) for aircraft and engine construction is stated to effect (*a*) a reduction of the structure weight of the aircraft, (*b*) a reduction in the weight of moving parts in an engine, with a consequent increase in permissible speed, and (*c*) an increase in the thermal efficiency of the engine.

Pistons in Aluminium, "Alpax" and Magnesium. (R. de Fleury, *Centes Rendus*, 182, 628-630 (1926), No. 10, *Physikal Ber.*, p. 1793 (1926). (10.23/4185)

The best piston metal is that of smallest ratio—thermal conductivity/(expansion × thickness). The shape is also important. The best results were obtained with a piston with top flat externally and with thickness internally increasing from centre to sides in a convex curve.

5 *Supercharging*

A Roots-Type Aircraft Engine Supercharger. (A. W. Gardiner, *J. Soc. of Automotive Industries*, September, 1926.) (8.62/4018)

A Roots-type supercharger is described and the results of laboratory and air tests are given. With full supercharging to 20,800ft. with a modified D.H.4 aircraft the absolute ceiling was increased by about 92 per cent. and the service ceiling by 100 per cent. as compared with an unsupercharged aircraft of the same type. Although no air cooler was used between supercharger and engine, the maximum carburettor air temperature at 20,000ft. was only 140°F.

Superchargers. (Description of Cozette supercharger, by L. Picard, *La Nature*, October 30th, 1926, pp. 285-288, 7 figures.) (8.62/4056)

To avoid the pressure of the vanes (palettes) on the outer casing with correspondingly high friction losses, an inner casing rotates with the same angular velocity as the blades, but concentric with the outer case (the stator).

Instead of the vanes rubbing on the whole circumference of the stator, they slide to and fro over a small arc of the inner casing.

Curves of power against r.p.m. are given for a small engine (1100 c.c.) 58 h.p. at 4500 r.p.m. with 800 gr./cm.^{2} pressure on the compressor = 0.8 atmospheres, against a max. h.p. of 33 at 4000 r.p.m. without supercharging.

6 *Cooling of Aircraft Engines*

Air-Cooled Engines in Naval Aircraft. (Com. E. E. Wilson, U.S.N., *The Journal of the Soc. of Automotive Engineers*, September, 1926.) (8.32/4199)

The article includes discussion on supercharging, radial and in-line engines, cooling efficiency, reliability, cost and production. It is stated that the U.S. Navy has been reluctant to use in distant service either the benzol-petrol blends or petrol treated with ethyl fluid, and that it has been endeavoured to avoid anything except domestic aviation petrol for general service. Air-cooled engine design is stated to have reached the point at which air-cooled cylinders are superior in cooling characteristics to water-cooled cylinders.

Thermo-Vapour Engine Cooling System. (C. H. Kenneweg, *J. Soc. of Automotive Industries*, September, 1926.) (8.34/4013)

After stating that steam-cooling represents the optimum that is obtainable in engine-temperature control, the author describes the thermo-vapour cooling system as a combination of the thermo-syphon system, in which boiling water is circulated rapidly through the engine-block, and a condenser system for dissipating the excess heat.

7 *Torsional Vibrations in Crankshafts*

(G. R. Goldsbrough, *Physikal. Ber.* 1621, 1926, Proc. Roy. Soc. A.109, 99-119, 1925, Nr. 749.) (8.22/4177)

The theory of torsional oscillations of slow-running shafts in reciprocating engines, especially of six-cylinder four-stroke cycle Diesel engines. The usual theory replaces pistons, rods, cranks, etc., by equivalent masses. The author

attempts to correct for these approximations by assuming that the individual shafts are rigid. The values of the critical speeds show moderate departures from the simple theory which may be insignificant in practice.

8 *Heat Transmission*

(8.57/4020)

The following two articles, published in the *Zeitschrift des Vereins Deutscher Ingenieure*, are abstracted in *Automotive Abstracts*, October 20th, 1926 :—

(*a*) Dr. W. Ludevici, *Z.V.D.I.*, August 21st, 1926. Results are given of the experimental determination of the semi-stationary boundary layer of flowing gases.

(*b*) Dr. H. Groeber, *Z.V.D.I.*, August 21st, 1926. This article deals generally with the laws of heat transmission. Formulæ are given dealing with the heat transmission in a bar or cooling fin, in a tube and from a radiating surface.

9 *Flow of Liquids and Gases*

Flow of Gases at High Speeds. (T. E. Stanton, *Physikal. Ber.*, p. 1611, 1926. Proc. Roy. Soc. London (A) 111, 306-339, 1926, No. 758.) (8.571/4190)

The following points are discussed in the first part of this comprehensive work :—

1. Axial and vertical pressure distribution in jets of various section, near the critical pressure.
2. Course of the flow, and rate of delivery, as functions of pressure for different cross sections.
3. Influence of size on similar nozzles.

The second part deals with out-flow at speed beyond that of sound, and with the measurement of pressure, and of velocity distribution without flow into still air.

Photographs of stationary waves are reproduced.

Electrically Operated Flowmeter. (*The Engineer*, November 5th, 1926.) (6/51/4016)

The flowmeter has been designed by the Brown Instrument Co. (U.S.A.) for the measurement of flow of liquids and gases. It is stated that no voltage regulator is required. All electrical parts and connections are external to the pressure chamber.

MATERIALS

10 *Light Alloys*

Magnesium Alloys. (Note in *Automotive Industries*, August 5th, 1926.) (10.21/4035)

Experments on various magnesium alloys have been reported upon by Portevin and Le Chatelier to the French Academy of Sciences. Among the binary alloys of magnesium studied, those containing nickel and copper seem to hold out the greatest possibility of practical utility, while of the ternary alloys those containing nickel-copper and aluminium-copper seem to be of the most interest.

Beryllium and its Production. (Abstracted in *Chemical Abstracts*, October 10th, 1926, from *Z. Metallkunde* 18, 159-60 (1926).) (10.21/4036)

A history of Beryllium and the developments leading up to the present German process, and its possible applications, particularly in the field of light alloys.

Acceleration Tests on Corrosion. (Note on p. 156, Supplement to *The Engineer*, October 29th, 1926.) (10.27/4023)

The note refers to the need of some corrosion test which should make it possible in a relatively short time to ascertain the corrosion resisting powers of aluminium and its alloys. The British "salt-spray" test is referred to. The method of test developed by Mylius, in Germany, is then discussed. (The Mylius test is described in *Zeitschr. f. Metallkunde*, May, 1925, and a recent application, more particularly to the study of intercrystalline corrosion, is described by Biegler in the September, 1926, number of the same Journal.) Mylius' test consists essentially in exposing samples of the metal to an oxidising solution of sodium chloride containing 1 per cent. of salt and 3 per cent. hydrogen peroxide.

Duralumin and its Corrosion. (W. Nelson. *Aviation*, 1st November, 1926.) (10.27/4175)

The article discusses the factors governing corrosion, corroding mediums (including salt atmosphere and the effects of contact with fuels), contact corrosion and induced corrosion.

Aluminium Solders. (Note on p. 154, Supplement to *The Engineer*, October 29th, 1926.) (10.27/4025)

The note refers to an article in *Zeitschr. f. Metallkunde* (July, 1926) in which it is stated that although the ordinary low melting solders are not satisfactory, the relatively high melting solders, consisting mainly of aluminium and applied with the aid of fluxes, have long been in entirely successful commercial use.

The Brinell Hardness of Lautal. (Note in *Zeitschrift fur Metallkunde*, October, 1926, p. 324.) (10.21/4042)

Tables are given showing the variation of Brinell hardness of Lautal with temperature, from 20°C. to 500°C.

11 "Stelliting" of Ferrous Metals

"Stelliting" to Resist Corrosion. (Note on p. 151 of Supplement to *The Engineer*, October 29th, 1926.) (10.15/4051)

It is stated that great interest is being taken in America in the new process of "Stelliting," *i.e.*, treating the surfaces of metals with an alloy consisting chiefly of chromium, tungsten and cobalt. Most ferrous metals are stated to respond to the treatment.

12 Dopes, Paints and Varnishes

(Trimmer H.R. Nitrocellulose rendered plastic by various media, *Farbe und Lack* 31, p. 441, 1926. Abstract in *Motorwagen*, 20th October, 1926, p. 717.) (10.42/4058)

Films of pure nitrocellulose are brittle and peel off by breaking or cracking.

The followng substances overcome the trouble:—

Tricreosyl phosphate (Lindol).
Pthalicacid-butyl-ester (also amyl- and dil-ethyl compounds).
Acetic Acid-dibutyl-ester (too easily sublimated).
Camphor (solid, miscible only by heating, very easily sublimated).
Triphenyl phosphate (easily sublimated, solid, miscible only by heating).
Castor oil not very soluble in usual solvents.

Suitable media should be free from smell and colour, chemically neutral, neither absorbent nor desiccatable, of high igniting temperature, and of good mechanical qualities.

13 Rubber

(*Industrial and Engineering Chemistry*, November, 1926.) (10.52/4193)

The above Journal contains a symposium on rubber, consisting of many articles on its manufacture and uses. One article deals with the direct use of rubber latex, especially vulcanised latex.

14 Timbers

The Characteristics of Various Woods. (Holz als Werkstoff, by Otto Frese, *Z.V.D.I.*, 9th October, 1926.) (10.31/4041)

The article deals with the characteristics of various kinds of woods, including spruce and pine, under different climatic conditions. Comparisons of weight and strength are made between (*a*) wood and (*b*) steel and light alloys.

15 Copper at Low Temperatures

(Letter from G. L. Alexander in *Nature*, October 23rd, 1926.) (19.12/4030)

The writer states that, during an experiment in which a small copper cylinder was immersed in liquid air, it was observed that a sudden re-evolution of gas took place after equilibrium had apparently been reached. It is pointed out that the phenomenon may be due to an allotropic change or to surface action and that the effect must cause a considerable loss in filling copper Dewar vessels with liquid air.

AERODYNAMICS

16 Fluid Motion

Turbulent Flow in Pipes. (M. Broszko (Warsaw), Zurich Congress, 1926.) (5.32/4200)

To investigate the phenomena of flow the assumption is made that the interaction between the boundary layer and the rest of the fluid is analogous to the wind on a liquid surface initially at rest.

When the critical speed is exceeded undulations are produced in the surface of the boundary layer which adheres to the walls, and these react on the main stream producing pulsations in the velocity.

From these assumptions, using H. A. Lorentz's theory, equations of motion were obtained in a form which gave complete agreement with measurements.

Drawing off the boundary layer by suction. (J. Ackeret dip. Ing. Gottingen, Zurich Congress, 1926.) (5.32/4201)

The boundary layer theory of Prandtl states that in many practically important cases of fluid motion there is a velocity potential, and the effects of viscosity may be neglected except in a relatively thin boundary layer where the reduced kinetic energy under certain circumstances leads to a reversed motion whereby the stream leaves the boundary.

Prandtl showed twenty years ago that the stream can be prevented from thus leaving the boundary by sucking away the boundary layer through suitably placed apertures in the body.

Only recently has this been tried experimentally with success.

It has been found by experiments on wing profiles, tubes and curved surfaces that the boundary can be removed effectively and configurations of flow obtained which were formerly impossible.

The sign of the pressure in a perfect liquid. (Prof. G. Bouligand (Poitiers), Zurich Congress, 1926.) (5.32/4202)

A mass of perfect liquid is in irrotational motion under gravity only. The Laplacian of the pressure is negative and consequently the lower limit of the pressure must be at the boundary surface. If the surface of a basin containing the liquid is cut only once by each vertical and is concave upwards it can be shown that the normal gradient of pressure is everywhere negative, excluding shock between fluid elements at the free surface, it follows that the pressure is everywhere positive in the fluid. Hence cavitation in the liquid can only take place at a rigid boundary.

17 Waves

Effect of divergent waves on the resistance of floats. (E. G. Barillon (Ing., Paris).) (5.34/4203)

The author finds Froude's results for a single hull insufficient for two or more floats, the sum of the individual resistances differing from the total resistance of a system.

He shows that by placing a single float in a suitable field of transversal waves due to a system of floats the additional resistance may be zero.

The periodicity (in space distribution) is the same for divergent and transversal waves.

The divergent waves are the controlling factor and the field of velocity of the system of floats as a whole dominates the phenomena.

18 Rotors

(Prandtl and Tietjens, Gottingen, *Berichte und Abhandlungen*, May, 1926, 13 pp. 100-102—4 plates.) (17.4/4180)

Cinematograph records of configuration of flow round cylinders non-rotating and rotating. By prolonging the exposure so as to obtain a streak from the motion of each particle of the indicator (lycopodium, aluminium filings, etc.) the instantaneous velocity field is recorded on each film in a clear manner. The succession of photographs enables the variation in the configuration of flow to be followed. The instability of the retarded fluid in the boundary layer is shown to have an important role. The motion is slow relatively to speeds in aeronautics, and is accelerated from rest during the making of the cinematograph record.

19 Airscrews

Test of a model propeller with symmetrical blade sections. (N.A.C.A. Technical Note 246. E. P. Lesly, Stanford University.) (5.42/4057)

Blade profile Gottingen No. 409, thickened up to double thickness at the hub for mechanical strength. Diameter 36in., chord 3in. at 2/5 radius, 2in. near tip, rounded off. Geometric pitch 2.7 feet. C.P. nearly constant at 0.6 chord.

(V/nD). Experimental pitch of no thrust	0.89	1.10	1.16
η efficiency	81%	81%	77%

Slightly better than Durand No. 3 at low values of $\sqrt{V^5/Pn^2}$.

AIRCRAFT DESIGN AND EQUIPMENT

20 Parachutes

"Salvator" Types. (*L'Aviazione*, September 30th, 1926.) (16.11/4060)

Two types are described. One is fitted to the aircraft fuselage and is automatic. It is stated to weigh 15½ lb., to have a speed of descent of 18 ft./sec

and to open in 1½ secs. The other type is fitted to the pilot's back and is opened automatically or by a lever fixed to the harness.

Parachute Test with complete Aircraft. (*Scientific American* (U.S.A.), November, 1926.) (16.11/4055)

An experiment is described in which an aeroplane weighing 1,800 lb., attached to a parachute 54 ft. in diameter, fell at an average speed of 38 ft./sec. and, it is stated, landed at considerably less than this speed. (The aircraft carried a pilot who is said to have made no attempt at gliding. The article refers to the possibility of similarly supporting the detachable passenger compartment of a civil aircraft, but it is not clear, either from the text or from the photographs in the article, that the aerodynamic forces on the wings were not materially responsible for the low landing speed.)

21 *Wing Design*

"The calculation of stresses in a frame consisting of two spars of variable section and an arbitrary number of cross ribs, the load being applied to one side of the frame." (*Cantilever Monoplane Wings.*) (*Zeitschrift fur Flugtechnik*, October 14th, 1926.) (5.21/4032)

The deformation in space is considered as a measure of the rigidity against bending and torsion of the framework as a whole. Application is made of the theory of statically indeterminate structures by the method of virtual displacement and the resulting equations are solved by the calculus of finite differences.

Aerodynamic and Strength Tests on the Wing of the Edo Metal Flying Boat. (By Alexander Klemin, *Aviation*, October 11th, 1926.) (5.21/4048)

The basis of the design of this wing is that the section has been so varied along the span as to provide spar depths corresponding to the loads imposed at different points of the wing span and, at the same time, to provide satisfactory aerodynamic characteristics. At the root there is a high camber, but comparatively little spar depth. The spar depth increases along the span until it is a maximum where the maximum bending stresses occur and then decreases to a minimum at the wing tip. It is claimed that elliptical lift distribution has been obtained, both at high and low angles of incidence, without wash-out.

22 *Fire Extinguishers*

The Bechard Fire Extinguisher. (*Les Ailes*, 14th October, 1926, No. 278.) (16.12/4024)

Experiments are described in which 25 per cent. of a "lubricating solution" was added to commercial tetrachloride, with a view to lessening the undesirable effects of the latter. Tests carried out with commercial tetrachloride and with the mixture showed that fires were extinguished with equal rapidity in each case and that the fumes emitted by the mixture were less disagreeable than those of the commercial tetrachloride.

23 *Wheel Brakes*

(*Scientific American* (U.S.A.), November, 1926, p. 391.) (5.55/4052)

It is stated that many American aircraft are now fitted with wheel brakes which reduce the landing run to about 100 ft. The Douglas T.2 has two large metal discs, one bolted to the outside of the wheel and the other mounted on the outer end of the axle in such a manner that it bears against the wheel disc when the brake pedal is depressed.

24 *Aircraft Carried in Submarines*

(*Scientific American* (U.S.A.), November, 1926, p. 392.) (5.16/4053)

Two photographs and a short description of stowing an aircraft in a tube and carrying it on a submarine.

WIRELESS

25 *Direction Finding*

The Stationary and Rotating Equisiqual Beacon. (W. H. Murphy and L. M. Wolfe, *J. of Soc. of Automotive Engineers*, September, 1926.) (13.4/4022)

Reference is made to the various means of direction finding and their respective advantages and disadvantages. The theory of the goniometer and types of loops are discussed, the equisiqual method of signalling is explained and the results of some experimental flights are given. The article is well illustrated.

26 *Pieso Electric Quartz Resonator*

(Abstract in *The Electrical Review*, October 29th, 1926, of a paper read by D. W. Dye before the Physical Society of London.) (13.21/4050)

The apparatus is described and experimental results are given. It is stated that a considerable future awaits development in the application of resonators and oscillators as frequency standards, filters, frequency controllers, etc.

27 *Short Wave Communication*

(By N. Wells, B.Sc., *Engineering*, October 22nd, 1926.) (13.7/4045)

The article deals with the theory of long distance beam transmission by means of short waves.

28 *Loud Speakers in Aircraft*

(*Aviation*, September 27th, 1926.) (13.31/4044)

At the National Air Races, Philadelphia, an aeroplane, flying at from 3,000 ft. to 5,000 ft., transmitted speech and music which was audible to the spectators on the ground. The aeroplane was a twin-engined Sikorsky S.29. No details of the equipment are given except that the apparatus weighs half a ton and requires two persons to operate it.

29 *Television from Aircraft*

(*Rivista Aeronautica. Anno II.*, No. 10, October, 1926.) (13.8/4186)

The possibility of transmitting sketches and diagrams from an aeroplane to earth by wireless. Discussion of the existing methods of transmission and of their extension to transmission from an aeroplane. Not realisable with present means, which require an appropriate adaptation to the new problem.

A transmission power of 300 to 500 watts is estimated as sufficient for a radius of 25-30 km., weight of installation 58 kg. not including the amplifier and transmitter, which require an additional 25 kg.

The engine ignition produces electromagnetic disturbance and the engine vibration produces mechanical disturbances.

A brief account of modern photo electric cells and examples of transmitted pictures, etc., is given.

ARMAMENT

30 *The Resistance of Rapidly Moving Bullets in Water*

(Abstracted in *Physikalische Berichte*, October 1st, 1926, from *Ann. d. Phys.* (4), 80, 232-244, 1926.) (9.16/4031)

Bullets were projected horizontally into water at speeds of from 150 metres/sec. to 650 metres/sec., and the loss of speed was determined. It was found that the square law of resistance held and that 2.6 per cent. of the momentum was lost when the bullet entered the water. It is stated that it appears probable that the resistance coefficient determined in these experiments (Reynolds Number 1,400,000 to 6,000,000) is substantially that which would be given by extrapolation from Prandtl's experiments on the resistance of bullets in air (Reynolds Number 370,000).

31 *Tracer Mixture*

(U.S. Patent 1593721 (July 27th, 1926), abstracted in *British Chemical Abstracts*, October 29th, 1926.) (9.35/4009)

The patent relates to a pyrotechnic composition consisting of an alkaline earth nitrate and carbonate, potassium nitrate, magnesium or aluminium, red lead and calcium, or other resinate to bind the components together and increase the brilliance.

32 *Spark Photography and its Application to Some Problems in Ballistics*

(U.S. Bureau of Standards Scientific Paper No. 508.) (9.16/4026)

The paper includes a description of the apparatus and the results (including a number of photographs) of experiments in which bullets were photographed when leaving the muzzle of a rifle and when passing through soap bubbles containing a mixture of hydrogen and air.

AIRSHIPS

33 *The Drag of Airships*

(N.A.C.A. Technical Notes No. 247 (September, 1926) and No. 248 (October, 1926).) (12.33/4019)

Report No. 247 is a summary of existing data. Report No. 248 deals with a method for finding the VL curve of any conventional type of hull, using data obtained from actual performance of airships. An empirical method is given for finding the drag coefficient of any bare airship hull of from 100,000 cu. ft. to 6,400,000 cu. ft. volume. It is concluded that the best model in the wind tunnel will probably, but not necessarily, be the best (lowest drag) full scale hull. The model and full scale VL curves may cross and again may re-cross at higher values of VL.

34 *Metal-Clad Airships*

(Annual Report of the Aircraft Development Corporation (U.S.A.), July 1st, 1926.) (12.64/4054)

This report includes a summary of the work done on the 200,000 cu. ft. metal-clad airship now under construction for the United States Navy.

MISCELLANEOUS

35 *Lighting Equipment for Airways, Airports and Aeroplanes*

(H. C. Ritchie and C. T. Ludington, *J. Soc. of Automotive Engineers*, September, 1926.) (6.62/4011)

This article (well illustrated) describes the various beacons used for the lighting of airways. Aeroplane lighting is also described, the types and locations of the lights on the aircraft being stated.

36 *Night Flying*

(W. L. Smith, *J. of Soc. of Automotive Engineers*, pp. 228-233, September, 1926.) (6.6/4015)

The article describes the operation of the night route between New York and Cleveland, and describes the instruments used and the arrangements made for emergency landing fields.

37 *Determination of Height above the Ground by Measurement of Electro-Static Capacity*

(Dr. Ing. H. List, Dessau, *Luftfahrt*, pp. 323-324, November, 1926.) (6.336/4176.)

An "auxiliary surface" is attached to the undercarriage and forms with the rest of the aeroplane a capacity which varies with distance from the earth. A sensitive indicator consists of a high frequency valve set, and a diagrammatic sketch of the recording needles and scales of the instrument shows high sensitivity at heights of 50 metres and less.

The special application is to indicate height near the ground in foggy weather.

38 *A Fabric Tension Meter for Use in Aircraft*

(Bureau of Standards Technologic Paper, No. 320.) (6.491/4027)

The instrument consists of an open chamber having an elliptical cross section and provided with a pressure gauge and deflection meter. Around its perimeter is a hollow rim perforated with small holes, by means of which the production of a partial vacuum in the rim causes the instrument to adhere firmly to the fabric and so isolates the portion of the fabric lying within the suction rim. Once isolated, the fabric is deflected inwards by means of a small suction until its deflection reaches a certain fixed value, when the operator holds the suction constant and reads the suction gauge. A method is devloped for measuring the tensions when the "modulus" of the fabric is not known.

39 *Aircraft Accidents*

(Article in *Flugsport*, 13th October, 1926.) (16.2/4047)

Details are given of an analysis by Brunart on the causes of 100 accidents in the French Air Services. It is stated that 54 were due to errors in operating the aircraft (*e.g.*, flying at an unnecessarily low height, taking off with an insufficient run and with a faulty engine), 22 were due to engine failure, 11 to failure of materials, 5 to bad weather conditions and 8 were due to unknown causes. It is interesting to note that, whilst engine failure was the second most important factor, the number of deaths due to this cause was the lowest of any of the classifications, the number of injuries being correspondingly high.

Analysis of Causes of Forced Landings. (*Mechanical Engineering*, November, 1926, p. 1162.) (16.2/4192)

Of the forced landings on the day and night New York and Chicago route in 1925, 21 per cent. were due to engine failure. The causes of engine failure were analysed as follows :—

	Per cent.
Cooling system	29
Ignition	27
Carburation and fuel	11
Lubrication	8
Miscellaneous	25

40 *Fluid Flow in Pipes of Annular Cross Section*

(D. H. Atherton, *Mechanical Engineering*, November, 1926.) (8.542/4178)

This object of the investigations reported in this paper was to determine the actual values of the friction coefficients for the flow of air, oil and water through pipes of annular cross-section. The apparatus and method of testing are described and the data and results of the tests are given in graphic and tabular form. It appears that the coefficient of friction corresponding to any given turbulence for both turbulent and viscous flow has a value for pipes of annular cross-section slightly higher than for pipes of circular cross-section when determined by the equivalent diameter formula.

41 *Wind Distribution above the Earth's Surface Calculated from Empirical Relations for Flow in Rough Tubes*

(L. Prandtl and W. Tallmien. *Zs. f. Geophysik Jahrgang* I., Hft. 1-2.) (6.23/4179)

The recent extension of experimental knowledge of the flow in rough pipes offers a method, by suitable analogy, of determining the direction of the wind over the surface of the earth according to the degree of irregularity of the surface.

A linear parameter of roughness, k, and an effective coefficient of viscosity, e (implying local turbulence and convection of vorticity), are introduced. From Karman's empirical equation for pipes, linear partial differential equations of 2nd and 4th order are obtained, and their solution, for varying height, is graphically represented by an equiangular spiral, the angle between the actual wind and the geostrophic wind being about 15° at the earth's surface and zero at great heights.

The tangential pressure of the wind on moving ice fields is referred to as the source of ice pack pressure on lee shores.

The following table is given :—

Nature of Earth's Surface.	k.	Tangential Pressures in kg. wgt./M².	$G/2\,\omega \sin\theta$ 10 m/s.	20 m/s.	30 m/s.
			Tangential Pressures in kgs./M².		
	.1 m		0.011	0.037	0.075
Fields and meadows ...	1. m		0.019	0.064	0.130
Uniformly wooded	10. m		0.033	0.111	0.225
Large towns	100 m		0.057	0.192	0.390

BRANCHES

In view of the increasing activities of the Branches of the Royal Aeronautical Society, it has been arranged to print, whenever possible, a series of special pages dealing with branch reports.

The following is a reprint of the general rules dealing with branches. These rules are to a certain extent elastic, so that they can be modified to suit local conditions :—

A Local Branch may be formed by the Council at the request of a number of local Members of the Society, and may be dissolved by the Council. It will be governed by its own Committee with a Chairman, who must be a Fellow or Associate Fellow. The Secretary must be a Fellow, Associate Fellow, or Associate. They will organise meetings, lectures, discussions and visits.

The Local Committee may enrol as Members of the Local Branch individuals unable to join the Main Society. Subscriptions of Members of the Main Society must be paid in full to Headquarters. Members of the Main Society who wish to take part in the activities of the Local Branch may be called upon for a small local subscription, which will be fixed by the Local Branch, and will be wholly available for local purposes. It is suggested that the local subscription should not exceed 5/- a year.

A Local Branch must consist of at least 20 Members, including Members of the Main Society.

A Local Branch shall be known as The ..... Branch of the Royal Aeronautical Society.

The assistance which the Society would give to a Local Branch would include :—

1. Assistance in the arrangement of lectures and discussions or the repetition of lectures and discussions already given elsewhere. The Society in London may be better in touch with those who would be able to give the best lecture on a selected subject than would the Secretary of the local organisation. The arrangement of lectures to be given by officers detailed by the Air Ministry is probably more easily made through London than direct. Expenses in connection with these lectures, etc., will be borne by the Local Branch.

2. Members of a Local Branch would be entitled to attend all lectures and discussions of the Society in London.

3. Members of a Local Branch would have the use of the Society's Library for reference.

4. One copy of the Journal will be supplied to each Local Branch for reference. A further copy will be supplied for each 50 Members in excess of the first 50. Local Members may each purchase, through their Local Branch, one copy of each issue of the Journal at trade price.

Data Sheets

As many members of branches are also Associates and Associate Fellows of the Society, particular attention is directed towards the notice about Data Sheets, which appears in the Preliminary Notices. These sheets will be available to all Associates and other Members of the main Society on application.

BRANCH NOTICES

COVENTRY BRANCH

(Hon. Secretary, F. MEADOWS, Esq.)

General Meeting

A General Meeting will be held in January, the exact date of which will be announced later.

Lecture

On December 7th, 1926, Mr. Handley Page, F.R.Ae.S., delivered a most interesting lecture on "The Stability and Control of Aircraft." There was an attendance of 250.

Mr. Handley Page remarked that now peace had come, or was alleged to have come, they had to turn their thoughts to important points dealing with the development of aircraft—not only for war purposes but for commercial purposes. The most important thing they had to deal with in the development of aircraft was to obtain greater stability and better control. To the popular mind the aeroplane was something inherently unstable, and the impression was that if the slightest thing went wrong the machine was liable to instantaneous disaster. Yet the idea that the control of an aeroplane was something analogous to walking on a tight rope was entirely erroneous.

The lecturer then proceeded to show how the stability and control of aircraft had developed right from the beginning of aeronautics in 1866, tracing the gradual improvements of various machines. A number of lantern slides added interest to the story. He said that the Wright Brothers in 1903 made the first successful power-driven machine, and they really discovered the secret of flight. The machine, however, was not stable.

Dealing with the modern problem of stability and control, he said that 95 per cent. of accidents were due to "stalling"—loss of sufficient speed to keep the machine in the air—and the whole question, therefore, resolved itself into making the aeroplane inherently stable. The recently devised slotted wing system of construction was the greatest step taken towards ensuring stability and control.

The lecturer, by means of diagrams and detailed explanations, revealed how advantageous was the slotted wing in promoting air safety. Numerous types of machines had been fitted with the slotted wing, and with the additional power of control given he thought they had the means of avoiding most of the accidents which had hitherto featured flying.

Remarking that every change in aircraft cost money, and that every new device meant the scrapping of a good deal of the old, the lecturer said in this country economy had to be considered, and they could not have all the things that were necessary. However, when it came to a question of economising where lives were concerned, economy was not economy. It seemed a crime that every precaution was not being taken to save lives in the air.

Dealing with the problem of machines being able to fly without a pilot, the lecturer said at the present time, commercial services machines between London and Paris had been fitted with controls, which allowed the machine to steer itself. The next few years were likely to see even greater developments, and they could look forward to the time when the public would get accustomed to air travel, and would regard it as a no more dangerous means of travel than going in a car or a train to their destination.

YEOVIL BRANCH

(*Hon. Secretary*, V. S. GAUNT, Esq.)

Formation and Lecture Programme

At a Council Meeting, held on December 14th, it was agreed to accede to the request of the Westland Aircraft Society to become the Yeovil Branch of the Royal Aeronautical Society. The branch is already in a very flourishing condition, over 125 members having joined it. An excellent series of lectures has been arranged as follows:—

"My African Flight," by Sir C. J. Quinton Brand, on January 7th, 1927.
"Magnetos," by A. P. Young, Esq. (of B.T.H.), on January 28th, 1927.
"Air-Cooled Engines," by A. H. R. Fedden, Esq., on February 4th, 1927.
"Airships," by H. B. Wyn Evans, Esq., on February 18th, 1927.
"Some Practical Aspects of Flying Boat Development," by Flt. Lieut. B. C. H. Cross, on March 4th, 1927.
"Test Flying," by Major L. P. Openshaw, on April 1st, 1927.
"Construction of Airscrews," by Mr. W. E. Parks, on April 22nd, 1927.

The above are general interest lectures. The following lectures have been arranged more particularly for ground engineers:—

"Testing of Materials," by Mr. Sutcliffe, on January 5th, 1927.
"Breakages, Strains and their Repair, etc.," by Mr. Gibson, on January 12th, 1927.
"Other Aircraft Timbers," by Mr. Carey, on January 19th, 1927.
"Glues," by Mr. H. Burdett (of Messrs. Improved Liquid Glues Co.), on January 26th, 1927.
"Engine Installation, Maintenance and Overhaul from the Ground Engineer's Point of View," by Mr. Somers, A.I.D., on February 2nd, 1927.
"Aircraft Steels," by Mr. Hopcroft (of Messrs. Firths), on February 9th, 1927.
"Aircraft Instruments," by Mr. J. E. Charlton (of Messrs. Smiths), on February 16th, 1927.
"Workshop Processes," by Mr. Goswell, on February 23rd, 1927.
"Workshop Processes," by Mr. Swetman and Mr. Millman, on March 2nd, 1927.
"Compasses—Installation and Swinging," by Mr. Robson, on March 9th, 1927.
"Wireless Installation," by Flight Lieut. F. J. Hooper, on March 16th, 1927.
"Equipment Installation," by Captain Keep, on March 23rd, 1927.
"The Wind Tunnel," by Mr. Widgery, on March 30th, 1927.

ROYAL AERONAUTICAL SOCIETY

Aims

The Royal Aeronautical Society exists for the furtherance of the Science of Aeronautics. It acts as the professional society or institution of qualified aeronautical engineers, conferring a recognised technical status on those qualified. The Society also organises discussions and publishes papers on subjects of importance in connection with the various branches of aeronautical engineering; encourages and assists technical students who desire to adopt the aeronautical profession for their careers; and provides an organisation wherein all interested in aeronautics, though not necessarily professionally connected with aviation, may meet together and have opportunities to keep themselves in touch with aeronautical affairs.

Membership

Membership of the Society is divided into the following grades:—

(*a*) **Students:** Persons under the age of 26 who are receiving a technical training such as will fit them in due course to become Associate Fellows.

(*b*) **Associates:** Persons employed in a technical capacity in the manufacture or operation of aircraft, who have had considerable experience in aeronautics but are not qualified to become Associate Fellows or Fellows. Entitled to use the letters A.R.Ae.S. after their names.

(*c*) **Associate Fellows:** Persons who have attained an acknowledged position in the Science of Aeronautics or allied sciences. Entitled to use the letters A.F.R.Ae.S. after their names.

(*d*) **Fellows:** Persons who have attained to considerable eminence in the Science of Aeronautics. Entitled to use the letters F.R.Ae.S. after their names.

(*e*) **Members:** Persons who are interested in the Science of Aeronautics and desire to support the Society. A non-technical grade.

Members in any of the above grades are entitled to attend the Society's lectures, receive the monthly JOURNAL free of charge (except Associates paying £1 1s. a year subscription) and consult and borrow books in the Society's Library. All grades, except Students, have full voting powers.

Activities

From October to April the Society holds a series of fortnightly meetings at which important papers are read by the leading authorities on aircraft design, operation and progress. All grades are admitted free to all these lectures, and tickets are issued to their friends on application to the Secretary. The lectures of the Society are reported in full in the JOURNAL, published monthly, which also contains important papers on aeronautical progress, and a regular epitome of the Society's activities. A classified list of articles which have appeared in the JOURNAL since 1917 may be obtained on application. Original papers of a fundamental character to the Science of Aeronautics are published from time to time as "Transactions of the Royal Aeronautical Society," and other important papers and reprints are also published.

The Society's Library is one of the finest aeronautical libraries in the world, containing many exceedingly rare aeronautical books, as well as being kept up to date. It is open to all members from 9.30 a.m. to 5 p.m. on weekdays, and 9.30 a.m. to 12 noon on Saturdays. The Library also contains the leading aeronautical and engineering papers of every country in the world.

The Society has a large collection of slides which are loaned to members for lecture purposes.